



US Army Corps
of Engineers

AD-A222 236



**DREDGING OPERATIONS TECHNICAL
SUPPORT PROGRAM**

TECHNICAL REPORT D-90-8

**REVISED PROCEDURAL GUIDE FOR
DESIGNATION SURVEYS OF OCEAN
DREDGED MATERIAL DISPOSAL SITES**

by

Willis E. Pequegnat, Benny J. Galloway

LGL Ecological Research Associates, Inc.
1410 Cavitt Street
Bryan, Texas 77801

and

Thomas D. Wright

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199



April 1990

Final Report

Approved For Public Release. Distribution Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

90 05 29 057

**Destroy this report when no longer needed. Do not return
it to the originator.**

**The findings in this report are not to be construed as an official
Department of the Army position unless so designated
by other authorized documents.**

**The contents of this report are not to be used for
advertising, publication, or promotional purposes.
Citation of trade names does not constitute an
official endorsement or approval of the use of
such commercial products.**

**The D-series of reports includes publications of the
Environmental Effects of Dredging Programs:
Dredging Operations Technical Support
Long-Term Effects of Dredging Operations
Interagency Field Verification of Methodologies for
Evaluating Dredged Material Disposal Alternatives
(Field Verification Program)**

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION / AVAILABILITY OF REPORT		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE			Approved for public release; distribution unlimited.		
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report D-90-8			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION See reverse.		6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION		
6c. ADDRESS (City, State, and ZIP Code) See reverse.			7b. ADDRESS (City, State, and ZIP Code)		
8a. NAME OF FUNDING / SPONSORING ORGANIZATION US Army Corps of Engineers		8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20314-1000			10. SOURCE OF FUNDING NUMBERS		
			PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.
			WORK UNIT ACCESSION NO.		
11. TITLE (Include Security Classification) Revised Procedural Guide for Designation Surveys of Ocean Dredged Material Disposal Sites					
12. PERSONAL AUTHOR(S) Pequegnat, Willis E.; Gallaway, Benny J.; Wright, Thomas D.					
13a. TYPE OF REPORT Final report		13b. TIME COVERED FROM TO		14. DATE OF REPORT (Year, Month, Day) April 1990	
				15. PAGE COUNT 262	
16. SUPPLEMENTARY NOTATION Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD GROUP SUB-GROUP					
			See reverse.		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) <p>This procedural guide is a revision of that issued in 1981 and has been prepared to meet the needs of the Corps of Engineers in conducting surveys for the designation of ocean disposal sites for dredged material. Basic purposes of the guide are to provide detailed information on evaluation of oceanographic parameters, collection of field samples, and performance of laboratory analyses. Another objective is to clarify the role of the monitoring program that may be instituted at each site pursuant to final site designation and to relate its content to the original site survey.</p> <p>Because the scientific content of the surveys is, in part, related to physical characteristics of the sites, such as size, depth of water, and distance from shore, these characteristics as they pertain to sites in the various Corps Districts are discussed in detail. There is also a discussion of the common features of the oceanography of the US continental shelf because over 80 percent of existing sites are located on the shelf. A substantial portion of the guide is devoted to the selection of variables to be measured in the field and the rationale for placement of sampling stations, as well as gear appropriate to various conditions.</p> <p style="text-align: right;">(Continued)</p>					
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL			22b. TELEPHONE (Include Area Code)		22c. OFFICE SYMBOL

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

6a&c. NAME AND ADDRESS OF PERFORMING ORGANIZATION (Continued).

LGL Ecological Research Associates, Inc.
1410 Cavitt Street
Bryant, TX 77801

and

USAEWES, Environmental Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

18. SUBJECT TERMS (Continued).

Dredged material disposal	Ocean waste disposal
Dredged material disposal sites	Public Law 92-532
Marine environment	Sampling
Marine Protection, Research, and Sanctuaries Act	Site surveys

19. ABSTRACT (Continued).

Detailed guidance is given on the preferred methods of sample analysis, including biological, physical, chemical, and geological methodologies. Suggestions are given for effective presentation of the field and laboratory data generated during the site survey. Because site designation does not, in itself, include the disposal of dredged material, the methodologies are, so far as possible, compatible with those used for the evaluation of material proposed for disposal. Although site designation, evaluation of material for disposal, and monitoring are separate activities, they are part of a continuum and should share common techniques so as to be cost-effective and of maximum technical validity.

Following an extensive listing of pertinent references, six technical appendixes are presented. These include a basic discussion of the nature of dredged material, factors reducing potential adverse effects of toxic substances in dredged material, and various specific analytical techniques. There is also a guide for at-sea operations, a basis for estimating survey costs, and a brief list of equipment suppliers.

The guide has been prepared in loose-leaf format so that revisions and changes as a result of regulatory modifications, development of new techniques, and changes in site status can be easily incorporated.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

PREFACE

This report was prepared by LGL Ecological Research Associates, Inc., under Contract No. DACW39-87-C-0080, as amended, and by the US Army Engineer Waterways Experiment Station (WES). The work was conducted as part of the Dredging Operations Technical Support Program (DOTS), which is sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE). The DOTS is managed by the WES Environmental Laboratory (EL) through the Environmental Effects of Dredging Programs (EEDP). Dr. Robert Engler was Program Manager for the EEDP, and Mr. Thomas R. Patin was Program Manager for the DOTS. Mr. Joseph Wilson, HQUSACE, was the Technical Monitor.

Authors of this document were Dr. Willis E. Pequegnat and Dr. Benny J. Gallaway of LGL Ecological Research Associates, Inc., and Dr. Thomas D. Wright of the EL. Portions of the report were derived from the September 1987 "Draft Final Guidance Manual for Ocean Site Designation and Management," prepared by Battelle Ocean Sciences Department and Tetra Tech, Inc., for the US Environmental Protection Agency (USEPA) under Work Assignment 48 of Contract No. 68-03-3319. Consultation on organic chemical analyses was provided by Dr. Charles Kennicutt of Texas A&M University.

Appendix C is reproduced from document EPA-503-8-90/002, "Draft Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters," prepared by the USEPA and USACE.

This study was conducted under the general supervision of Dr. Lloyd H. Saunders, Chief, Contaminant Mobility and Regulatory Criteria Group; Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division; and Dr. John Harrison, Chief, Environmental Laboratory.

COL Larry B. Fulton, EN, was Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

This report should be cited as follows:

Pequegnat, Willis E., Gallaway, Benny J., and Wright, Thomas D. 1990. "Revised Procedural Guide for Designation Surveys of Ocean Dredged Material Disposal Sites," Technical Report D-90-8, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

DTIC COPY INSPECTED 1	Accession For	
	NTIS GRA&I	<input checked="" type="checkbox"/>
	DTIC TAB	<input type="checkbox"/>
	Unannounced	<input type="checkbox"/>
	Justification	
	By	
	DTIC	
	Availability Codes	
	/or	
	A-1	

CONTENTS

	<u>Page</u>
PREFACE	i
CONVERSION FACTORS, NON-SI TO SI (METRIC)	
UNITS OF MEASUREMENT	v
PART I: INTRODUCTION	1
BRIEF OVERVIEW OF DREDGING AND DISPOSAL	1
WHY A PROCEDURAL GUIDE IS NEEDED	2
ISSUANCE OF REGULATIONS AND CRITERIA	
GOVERNING OCEAN DUMPING	2
SELECTION AND DESIGNATION OF DISPOSAL SITES	3
PROMULGATION OF THE FINAL RULE	5
NATURE OF OCEAN SURVEYS OF DREDGED MATERIAL	
DISPOSAL SITES	6
PROBABLE USERS OF THE GUIDE	8
OBJECTIVES OF THE GUIDE	9
SAMPLING PHILOSOPHY	10
PART II: GROUPING OF SITES BY GEOGRAPHIC AND	
ENVIRONMENTAL CHARACTERISTICS	15
INTRODUCTION	15
ATLANTIC COAST	15
GULF OF MEXICO COAST	21
PACIFIC COAST	24
ALASKA - ALASKA DISTRICT	29
HONOLULU DISTRICT, PACIFIC OCEAN DIVISION	30
CARIBBEAN TERRITORIES OF US VIRGIN ISLANDS AND	
PUERTO RICO - JACKSONVILLE DISTRICT	31
PART III: GROUPING OF SITES BY PHYSICAL CHARACTERISTICS	33
INTRODUCTION	33
CORPS DISTRICTS	33
SITE CHARACTERISTICS SUMMARY	33
PART IV: ANALYSIS OF SITES BY DISTRICT	39
INTRODUCTION	39
ATLANTIC COAST	39
CARIBBEAN	44
GULF COAST	46
PACIFIC COAST	50
PACIFIC OCEAN	54
PART V: SELECTING AN OCEAN DISPOSAL SITE FOR	
DREDGED MATERIAL	56

	<u>Page</u>
INTRODUCTION	56
LEGAL AND OTHER CONCERNS REGARDING SITE SIZE	61
OCEANOGRAPHIC CONSIDERATIONS	62
SITE DESIGNATION PROCESS	68
SCREENING TECHNIQUE FOR LOCATING AN OCEAN DISPOSAL SITE	68
COMPUTERIZED SYSTEM FOR SITE DESIGNATION	71
DEALING WITH EXISTING SITES	74
RELATED LITERATURE	74
PART VI: SELECTION OF VARIABLES TO BE MEASURED IN THE FIELD FOR SITE SELECTION AND DESIGNATION	75
GENERAL	75
SURVEY PHILOSOPHY	75
LEGAL AND REGULATORY REQUIREMENTS	76
ANALYSIS OF OCEAN SURVEY PLAN	78
MEASUREMENTS IN THE WATER COLUMN AT AND NEAR THE DISPOSAL SITE	79
MEASUREMENTS OF THE BENTHIC REGION	83
OTHER MEASUREMENTS	92
PART VII: IMPLEMENTATION OF THE SAMPLING PROGRAM	96
INTRODUCTION	96
VESSEL REQUIREMENTS	96
PRESURVEY PLAN	100
DOCUMENTATION	101
SAMPLING EQUIPMENT AND ITS USE	102
LABELING	107
SAMPLING AND PRESERVATION	108
PART VIII: PRESENTATION OF LABORATORY AND FIELD DATA	114
GENERAL	114
DESCRIPTIVE TREATMENT OF WATER COLUMN DATA	114
ANALYSIS OF SEDIMENT DATA	118
ANALYSIS OF ENVIRONMENTAL DATA	124
ANALYSIS OF DATA ON BENTHIC BIOTA	126
APPLICATION OF CRITERIA FOR DATA INTERPRETATION	152
PART IX: MONITORING OF MARINE DREDGED MATERIAL DISPOSAL SITES	156
ELEMENTS OF A SITE MANAGEMENT PLAN	156
UNACCEPTABLE ADVERSE EFFECTS	157
THE ROLE OF PREDICTION IN MONITORING	160
PROSPECTIVE VERSUS RETROSPECTIVE MONITORING	160
PRODUCING A MONITORING PLAN	161
COMPARISON OF TIERED AND NONTIERED MONITORING PROGRAMS	165

	<u>Page</u>
MONITORING OF POSTDISPOSAL SUCCESSION OF THE INFAUNA	167
MONITORING THE FISHERY POTENTIAL OF THE DREDGED MATERIAL MOUND	171
WHEN ALL ELSE FAILS	172
REFERENCES	174
APPENDIX A: THE NATURE OF DREDGED MATERIAL	A1
APPENDIX B: FACTORS REDUCING ADVERSE EFFECTS OF TOXIC SUBSTANCES IN DREDGED SEDIMENTS	B1
APPENDIX C: PHYSICAL ANALYSES OF SEDIMENT AND CHEMICAL ANALYSES OF SEDIMENT, WATER, AND TISSUE SAMPLES	C1
APPENDIX D: CHIEF SCIENTIST'S GUIDE FOR AT-SEA OPERATIONS	D1
APPENDIX E: BASIS FOR ESTIMATES OF SURVEY COSTS	E1
APPENDIX F: LIST OF EQUIPMENT SUPPLIERS	F1

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
fathoms	1.8288	meters
feet	0.3048	meters
feet per mile	0.1893935	meters per kilometer
gallons (US liquid)	3.785412	cubic decimeters
inches	2.54	centimeters
knots (international)	0.5144444	meters per second
miles (US statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
square feet	0.09290304	square meters
square miles (US nautical)	3.429904	square kilometers

REVISED PROCEDURAL GUIDE FOR DESIGNATION SURVEYS OF OCEAN DREDGED MATERIAL DISPOSAL SITES

PART I: INTRODUCTION

BRIEF OVERVIEW OF DREDGING AND DISPOSAL

The Corps of Engineers (CE) is presently responsible for maintaining over 25,000 miles* of navigable waterways that service over 155 commercial ports and more than 400 small boat harbors, all of which are valuable for commercial, defense, or recreational purposes. Corps and private projects require the dredging of nearly 465 million cubic yards of sediment each year, at a cost of about \$725 million (Pequegnat 1986). Most of this material originates from CE projects that have been authorized by the Congress.

About 30 percent of all dredged material is disposed of in marine environments. Some 55 percent of this is placed in estuaries, and the remainder in coastal waters or the open ocean. It is perhaps surprising to note that only some 24 of a total of 108 sites are used for about 95 percent of all dredged material disposed of in coastal waters and the open ocean. It is anticipated that pressure to use marine environments for dredged material disposal will continue or increase, especially as more and more harbor deepening projects are undertaken. Accordingly, it is estimated that harbor development and channel deepening projects now in hand will alone generate more than 50 million cubic yards of material per year until the turn of the century. It is estimated that about 45 percent of this material will be disposed of in coastal waters and the open ocean.

No disposal option is categorically better than another, from an operational, economic, environmental, or social standpoint (Saucier et al. 1978). Extreme variability and some uncertainty among these factors necessitates site-specific and often subjective evaluations of most dredging and disposal projects (Francingues et al. 1985).

Government policies that attempt to curb pollution in freshwater and marine environments have indirectly encouraged dredged material disposal in upland containment areas. Disposal in such areas is generally more costly than other options, a fact that creates some tension between regulatory requirements and economics, since costs are of necessity of considerable importance to the CE. However, this option is not always safe, since upland containment areas have been suspected to be sources of saltwater intrusion and other ground-water contamination (Gambrell, Khalid, and Patrick 1978; Pequegnat 1986; Engler 1988**). No matter what disposal option is considered, finding a disposal site for dredged material in any environment is becoming more difficult for Federal agencies and local sponsors. In fact, several coastal Corps Districts do not hesitate to advise that finding suitable disposal sites is their most difficult problem. As a result, they are tending more and more to elect ocean disposal as the favored option.

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page v.

** Personal Communication, Robert M. Engler, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

WHY A PROCEDURAL GUIDE IS NEEDED

This procedural guide or manual is based upon the parent volume published by the CE in 1981, entitled "Procedural Guide for Designation Surveys of Ocean Dredged Material Disposal Sites" (Pequegnat et al. 1981). Whereas the 1981 manual was directed primarily toward recommending techniques and parameters to be followed in carrying out ocean surveys for the purpose of designating an ocean site for disposal of dredged material, this volume discusses site selection and management practices, including monitoring. Although this guide has been prepared primarily to meet the needs of the CE, past experience indicates that it will be a reference volume for any person involved with ocean disposal. Whereas in 1981 there were about 130 ocean sites for dredged material, today there are 108. Some sites were removed from consideration by Corps Districts because they had never been used or rarely so, while others were found to be 404 sites governed by the Clean Water Act.

Before final designation can be conferred upon a site, full environmental documentation must be prepared and approved by the US Environmental Protection Agency (USEPA) for each site or for each group of generically related sites. Prior to preparation of these documents, special oceanographic surveys have been or very likely will have to be carried out. Adequate information should exist for most interim designated sites and most proposed new sites, but some new sites may require field surveys. These surveys are usually very general in compliance with stipulations of the Final Revision of the Regulations and Criteria governing ocean dumping, which was published by the USEPA in 1977. Such surveys are justified in part as providing data that describe the environment of the site and its environs, but they are much too general to be followed as the basis for a monitoring program, as monitoring is based upon hypothesis testing to address specific problems. Thus, one of the purposes of this guide is to present the scientific aspects of such surveys, including selection of the oceanographic parameters to be measured, as well as how to carry out the measurements in the field and conduct analysis in the laboratory.

Another goal of the guide is to clarify the role of the monitoring program that may be instituted at each site pursuant to final designation and to relate its content to the original ocean survey. Having detailed how to obtain data, we would be remiss in not discussing how to work with the data generated by the surveys and the monitoring program. Statistical treatments are not in and of themselves able to create a defensible document. Rather, such manipulations are only tools that the environmental manager must understand in order to employ good judgment.

At times we have been surprised to find that people who must judge the effects of ocean dumping of dredged material have only a cursory knowledge of the physicochemical nature of even a generic dredged material. Accordingly, we have included, in Appendixes A and B, short treatises on dredged material and how it acts in different receiving environments.

ISSUANCE OF REGULATIONS AND CRITERIA GOVERNING OCEAN DUMPING

Disposal of dredged material from vessels at sea is permitted by the CE under the provisions of Section 103 of the Marine Protection, Research, and Sanctuaries Act, but permits are granted only under criteria that USEPA established in accordance with

Section 102(a). Promulgated on 11 January 1977, the original criteria and regulations have been revised considerably; however, as noted above, the revisions have not been published by the USEPA in the **Federal Register**. Nevertheless, applications and authorizations for dredged material disposal permits are evaluated by the CE in accordance with the criteria for evaluating environmental impacts set forth in Part 227 of the 1977 Regulations and Criteria. These criteria stipulate that the disposal of dredged material will present:

- a. No unacceptable adverse effects on human health and no significant damage to the resources of the marine environment.
- b. No unacceptable adverse effect on the marine ecosystem.
- c. No unacceptable adverse, persistent, or permanent effects due to the dumping of the particular volumes or concentrations of these materials.
- d. No unacceptable adverse effect on the ocean for other uses as a result of direct environmental impact.

SELECTION AND DESIGNATION OF DISPOSAL SITES

The designation of dredged material disposal sites in the ocean will be executed by the USEPA or the CE and will be based on:

Environmental studies of each site, regions adjacent to the site, and on historical knowledge of the impact of dredged material disposal on areas similar to such sites in physical, chemical, and biological characteristics (Regulations and Criteria, Part 228.4).

The results of these studies will be used to prepare appropriate environmental documentation. An important provision regarding the number of separate impact assessments a Corps District needs to prepare for final designation of disposal sites in its jurisdiction states:

An environmental impact assessment for all sites within a particular geographic area may be prepared based on complete disposal site designation or evaluation studies on a typical site or sites in that area. In such cases, sufficient studies to demonstrate the generic similarity of all sites within such a geographic area will be conducted (Regulations and Criteria, Part 228.4).

The establishment of generic similarity would depend upon related sediment beds, biota, and those other oceanographic parameters that would determine the fate of the disposed dredged material.

All studies for the evaluation of interim sites and potential selection of new dredged material disposal sites will be conducted in accordance with five general and eleven specific criteria.

General Criteria (40 CFR 228.5)

General criteria for selection of disposal sites are as follows:

- a. The dumping of materials into the ocean will be permitted only at sites or in areas selected to minimize the interference of disposal activities with other activities in the marine environment, particularly avoiding areas of existing fisheries or shellfisheries, and regions of heavy commercial or recreational navigation.
- b. Locations and boundaries of disposal sites will be so chosen that temporary perturbations in water quality or other environmental conditions during initial mixing caused by disposal operations anywhere within the site can be expected to be reduced to normal ambient seawater levels or to undetectable contaminant concentrations or effects before reaching any beach, shoreline, marine sanctuary, or known geographically limited fishery or shellfishery.
- c. If at anytime during or after disposal site evaluation studies it is determined that existing disposal sites presently approved on an interim basis for ocean dumping do not meet the criteria for site selection set forth in 40 CFR 228.5-228.6, the use of such sites will be terminated as soon as suitable alternate disposal sites can be designated.
- d. The sizes of ocean disposal sites will be limited in order to localize for identification and control any immediate adverse impacts and permit the implementation of effective monitoring and surveillance programs to prevent adverse long-range impacts. The size, configuration, and location of any disposal site will be determined as a part of the disposal site evaluation or designation study.
- e. USEPA will, wherever feasible, designate ocean dumping sites beyond the edge of the continental shelf and other such sites that have been historically used.

Specific Criteria (40 CFR 228.6)

In addition to other necessary or appropriate factors determined by the Administrator, the following factors will be considered:

- a. Geographical position, depth of water, bottom topography and distance from coast.
- b. Location in relation to breeding, spawning, nursery, feeding, or passage areas of living resources in adult or juvenile phases.
- c. Location in relation to beaches and other amenity areas.
- d. Types and quantities of wastes proposed to be disposed of, and proposed methods of release, including methods of packing the waste, if any.
- e. Feasibility of surveillance and monitoring.
- f. Dispersal, horizontal transport, and vertical mixing characteristics of the area, including prevailing current direction and velocity, if any.
- g. Existence and effects of current and previous discharges and dumping in the area (including cumulative effects).
- h. Interference with shipping, fishing, recreation, mineral extraction, desalination, fish and shellfish culture, areas of special scientific importance and other legitimate uses of the ocean.

- i. The existing water quality and ecology of the site as determined by available data or by trend assessment or baseline surveys.
- j. Potentiality for the development or recruitment of nuisance species in the disposal site.
- k. Existence at or in close proximity to the site of any significant natural or cultural features of historical importance.

PROMULGATION OF THE FINAL RULE

On 26 April 1988 the US Army Corps of Engineers published the Final Rule for operation and maintenance of Corps Civil Works projects involving the discharge of dredged material into waters of the United States or ocean waters (33 CFR Parts 209, 335-338).^{*} This action replaced 33 CFR 209.145 dealing with these operations and complies with Executive Orders, court decisions, and policy changes that have occurred since the previous regulations were published on 22 July 1974. This new regulation provides current procedures for compliance with state water quality certification, coastal zone consistency, and other environmental requirements of Corps maintenance dredging and disposal operations. This regulation will enable the CE to more effectively implement the relevant provisions of the Clean Water Act (CWA) and Ocean Dumping Act (ODA) when carrying out projects involving dredged material relocation into waters of the United States and ocean waters.

The policy statement in Part 335 states unequivocally that the CE will undertake operations and maintenance activities with full consideration being given to costs and engineering feasibility in concert with its environmental responsibilities. Emphasis is placed upon the dictum that when evaluating such projects the CE will consider all practicable and reasonable alternatives on an equal basis. This will also include consideration of National Economic Development (NED) policy as, for example, in establishing the zone of siting feasibility. Although it may be feasible and practicable to designate a site off of the continental shelf, the constraints of the NED must be taken into account. The conditionality of this dictum means that final decisions or alternatives will likely be made in many cases by District Engineers.

The Federal Standard

As practice has shown, difficult questions have arisen as to the respective roles and decision authorities of States and the Federal Government in actions involving the relocation (disposal) of dredged material. The Federal Standard as described in 33 CFR 335-338 is simply the disposal alternative identified by the CE which complies with Federal environmental laws and regulations in the least costly manner consistent with sound engineering practices and the NED. All negotiations of the CE with state agencies and public organizations will use this alternative as the point of reference.

^{*} Federal Register, Vol 53, No. 80, pp 14902-14920.

Selection of Dredged Material Disposal Sites

Under provisions in the ODA, both the Secretary of the Army (Section 103) and the USEPA (Section 102) have authority to designate dredged material disposal sites in the Territorial Sea and ocean waters. The Secretary expects to continue to exercise this site selection authority if and when the situation requires such action.

Compliance with FWCA, ODA Sanctuaries, and National Historic Preservation Act

Where the Fish and Wildlife Coordination Act applies, the District Engineer is required to consult with the Regional Directors of the US Fish and Wildlife Service and the National Marine Fisheries Service, as well as with the head of the relevant state agency. In general the District Engineer is expected, if necessary and feasible, to modify the proposed operation in order to lessen possible damage to fish and wildlife resources.

Where a proposed disposal is scheduled to take place in a marine sanctuary established by the Secretary of Commerce under Section 302 of the ODA, the project should be evaluated for the impact on the marine sanctuary. Certification of consistency with Title III of the ODA and the regulations circulated by the Secretary of Commerce to control activities within the marine sanctuary should be obtained from the Secretary.

The National Historic Preservation Act requires that the State Historic Preservation Officer be given an opportunity to comment on projects that may impact historic properties within the Territorial Sea. Such historic properties include, but are not limited to, ship wrecks and archeological sites.

Practice and Procedure

Part 337 of 33 CFR provides guidance, principally to the District Engineer, regarding actions required of the CE when dealing with the general public or states. Detailed information is given on the nature and issuance of public notices. District Engineers are also advised to establish joint notification procedures through development of Memoranda of Agreement (MOA) with states, primarily to minimize administrative duplication.

Guidance is also given on authorization of certain categories of activities on a regional or possibly nationwide basis. This authorization will allow compliance with all environmental laws, including state concerns, through a single process for a category of activities. When evaluation of general categories of activities is complete, and all matters of coordination and certification, including completion of appropriate environmental document, are in hand, a statement of findings will be prepared. In cases involving an Environmental Impact Statement (EIS), a record of decision will be prepared in accordance with 33 CFR, Part 230.

NATURE OF OCEAN SURVEYS OF DREDGED MATERIAL DISPOSAL SITES

Ocean Surveys Subject to Reasonable Modification

In our discussions with several individuals in both the CE and USEPA, it was evident that some believed that any survey dealing with ocean dumping had to include all of the

items listed in the guidelines in Part 228.13 of the Regulations and Criteria on Ocean Dumping issued by the USEPA in the 11 January 1977 **Federal Register**. This, however, is not the case. There is a limitation of sorts in Part 228.1 (applicability) that is easily overlooked; it says

The criteria of this Part 228 are established pursuant to Section 102 of the Act and apply to the evaluation of proposed ocean dumping under Title I of the Act. The criteria of this Part 228 deal with the evaluation of the proposed dumping of material in ocean waters in relation to continuing requirements for effective management of ocean disposal sites to prevent unreasonable degradation of the marine environment from all wastes being dumped in the ocean. **This Part 228 is applicable to dredged material disposal sites only as specified in Parts 228.4(e), 228.9. and 228.12.**

The boldface has been added for emphasis. The key words in the above are "applicable" and "only." Part 228.4(e) calls for environmental studies prior to final designation and requires that the selection of new sites shall follow the criteria that were listed above, but Part 228.12 states that the interim sites are not burdened by the criteria for size and usage given above. Moreover, wherever reference is made to the content of an ocean survey, the phrase "applicable requirements" is inserted. Clearly this is a judgmental issue and one that provides for considerable latitude in formulating a survey program for dredged material disposal sites. It is obvious that it is desirable to have a high degree of uniformity in these surveys; thus, this guide has another important function to perform.

Oceanographic Characterization of the Site Through the Baseline Survey

The thrust of the Environmental Assessments and EISs for site designation relates to a thorough analysis of the impacts that may accompany the disposal process. In large measure, the physical extent of these impacts, both within and outside the site, will depend upon the oceanographic nature of the site. Although in most instances sufficient data on interim sites may already exist from which an EIS can be prepared, it is anticipated that oceanographic surveys may have to be conducted at some sites. These surveys must be carried out on a sound scientific basis, within economic and time constraints. They will be designed to fit very practical needs, producing data from which to characterize the site environs in terms of those particulars that are closely related to the impacts of dredged material disposal. Both qualitative and quantitative data will be appropriate for site characterization, but nothing of significance can be added to the survey's plan, unless the derived data can be related to impacts or impact reduction.

Data Base for a Monitoring Effort

Following designation, there is the possibility that the District Engineer may require that monitoring be done. It is important that standard, accepted techniques be used during designation so that the data will also be useful for potential monitoring.

In the first place, the monitoring survey must sample variables that can be quantified with a reasonable degree of accuracy. Even though a variable may be reported in numerical terms, such data may be worthless in a monitoring effort if the sampling gear and technique carry such a high built-in variance that there can be little confidence that two sets of

data taken at the site have any meaning if they are the same or different. For instance, sampling of the epifauna with an ordinary otter trawl will produce data that are qualitative but not very quantitative simply because the size of the net aperture, if it is open at all, depends in part on the speed of tow. Qualitative data may be adequate for site designation but not for the monitoring effort. A better approach to megaepifaunal sampling may be to employ a fixed-aperture beam trawl, as discussed in Part VII.

The above consideration suggests a second significant difference between a site designation and a monitoring survey: the latter will deal with the measurement of a smaller number of parameters. Thus, the selection of variables to be included in the monitoring study will depend upon analysis of important impacts and on knowledge of appropriate quantifiable parameters. The bottom line, so to speak, of the concern with impacts centers in the biological aspect of the environment. However, chemical and physical variables may often be used rather than direct biological measurements. When this is done, there must be a known relationship between the variable and an effect. It is unlikely that dredged material will have any serious or lasting effect on temperature, salinity, dissolved oxygen, or even turbidity in the water column. Thus, although these parameters are quantifiable and excellent for site characterization, they are of little critical value for monitoring. On the other hand, there is a strong possibility that continued disposal will affect some organisms in measurable ways. In almost all cases, there will be physical effects, such as burial. A parameter of particular concern today is bioaccumulation. The uptake of materials from the environment is a perfectly normal function and is of little concern when the compounds are utilized or broken down (metabolized) by the organism. When, however, the materials are not metabolized or discharged from the body but are stored unchanged in one or more of the organism's tissues, the accumulation takes on new importance, especially if the material is a toxic metal, polychlorinated biphenyl (PCB), organohalogen (i.e., chlorinated hydrocarbon), or petroleum hydrocarbon.

Food webs in the marine environment are so little understood that even if bioaccumulation occurs in a seemingly unimportant species, it may prove to be the food of a species harvested by man. In such cases it is important to determine whether the presence of the toxicant in one of its metabolic pools is stressing the organism to the point of affecting its general welfare and reproductive capacity. An approach to this determination that is now used by Woods Hole Oceanographic Institution and some National Oceanic and Atmospheric Administration laboratories, but which is considered to be an optional survey item, involves determination of scope for growth and benthic community assessment, both of which respond to the presence of particular toxicants and reveal the presence or absence of stressful conditions (see Gentile et al. 1988). If a District chooses to include these in situ bioassay and bioaccumulation techniques in its survey plan, they will yield data that are applicable to both designation and monitoring surveys.

PROBABLE USERS OF THE GUIDE

Throughout the preparation of this guide, the authors have been influenced by the belief that this document will have two very different groups of users. One group will be personnel of the CE, particularly in Corps Districts, who must issue Requests for Proposals for survey work and must therefore understand the nature of a survey in order to prepare scopes of work and eventually to evaluate proposals. This understanding, which must be

shared by USEPA personnel and affected marine interests as well, is also necessary for sound interpretation and decision making on the basis of survey results.

The second group of users will be those scientists and technicians who have been contracted with to carry out the surveys and analyze the data. Accordingly, the guide has been formulated to satisfy the requirements of both groups.

OBJECTIVES OF THE GUIDE

It is to be expected that a procedural guide will have many objectives, most of which are reflected in the table of contents. As stated above, the guide is designed to meet the needs of two distinctly different groups of users; hence, the objectives stated below are the authors' understanding of the needs of the users.

- a. Describe and tabulate the general geographic location and physical characteristics of the present disposal sites, designated or not.
- b. Describe the physiographic and oceanographic dimensions of a model dredged material disposal site in the marine environment.
- c. Provide a synthesis of the basic oceanographic processes going on at and around this exemplar marine disposal site.
- d. Discuss the measurements and samples to be taken in a field survey of a disposal site that will yield the data needed for preparation of adequate environmental documentation relating the discussion to potential impacts.
- e. Recommend and describe the types of oceanographic equipment needed to carry out the measurements and sampling.
- f. Describe how to carry out the field sampling, noting why the measurement of some variables is deemed unnecessary, and how to process the samples in the field.
- g. Provide the basis for selecting the number and position of stations at which samples of each variable will be taken.
- h. Discuss the nature of the sites in each Corps District and recommend sampling programs.
- i. Describe procedures to be followed in the laboratory phases of the required analyses.
- j. Provide useful guides for processing the data and interpreting the significance of the findings.
- k. Finally, provide suggestions on the nature of a monitoring program and how to carry it out. Actually this should be done even prior to mounting the initial survey cruises (see Part IX).

General Nature and Oceanographic Setting of Sites

Its physical characteristics, including among other things its size, topography, and distance from shore, dictate the intensiveness of the field survey undertaken to characterize a site for designation. As is explicit in the specific criteria stated above, the fate or ultimate disposition of the dredged material disposed at a marine site will determine the full range of the impacts that are a foremost consideration in site evaluation. Because the ultimate

disposition of the material depends in part upon the oceanographic characteristics of the region in which the site is located, it is felt that some general discussion of the setting of the majority of sites is appropriate here. A more specific discussion of oceanographic conditions occurring at the sites within Corps Districts will be undertaken in Part II.

Physical Characteristics of Sites

Most dredged material disposal sites are small. Some 82 percent are less than 2.0 square nautical miles in area, and over half of these actually cover less than 0.5 square nautical mile. General criterion d cited on page 4 limits the size of disposal sites to localize impacts and promote the relative simplicity of the site survey and feasibility of monitoring. Other factors that simplify survey sampling and thus reduce the time required to complete the study are proximity to shore and shallow depth. The bulk of the present marine dredged material sites are within 5 nautical miles of shore. Sixty percent are located in water less than 20 m deep, and only 18 percent are deeper than 100 m. In a few cases the center of the site is less than 3 m deep, requiring that sampling be done from a relatively small vessel. The majority of sites are close to the sources of dredged material. This is even true of sites that are considerable distances offshore, as at the Mississippi River Gulf outlet, because the sites are adjacent to and parallel with the dredged channel. Because of the provisions of 40 CFR 228.5(e), there have been recent expressions of concern from resource agencies to designate sites beyond the continental shelf. Although technically feasible, economics and other factors may render such designation infeasible.

Proximity to shore, shallow depth, and small area facilitate the task of conducting oceanographic studies of the sites. Shallow depth means that the water column is either uniform from top to bottom throughout the year or at most develops a two-layered system during the warm months. Shallow depth and proximity to shore also mean that the dredged material sites are influenced by wind, waves, and swell. Data on both of these factors are frequently available in the literature for the general areas where sites are located; if not, hindcasting from historical meteorological data may be used. Expensive and drawn out water-movement field studies are not generally warranted.

SAMPLING PHILOSOPHY

Release Zone Versus Extended Impact Zone

One cannot establish or evaluate a sound sampling program without an understanding of the probable full oceanographic dimensions of the site or sites to be sampled, and without a working knowledge of the oceanographic factors that determine the magnitude of these dimensions. In this section the authors propose to examine the concept of the **extended impact zone**, because it must be understood in order to justify the number and position of sampling stations. In a later section, the oceanographic systems involved shall be examined.

Definition of extended impact zone

If dredged material is disposed on land, the environment of the disposal site may be thought of in terms of the site's specific location, topography, surface and subsurface geology, and drainage characteristics. For several reasons the marine disposal environment cannot be characterized so simply, nor can its effective location be pinpointed so accurately. A land site is planar, having two dimensions, and in a legal sense so is the marine site.

In actuality, however, the marine site is three-dimensional, comprised of the water column or pelagic component and the bottom or benthic component. These form an imaginary rectilinear column.

To understand impacts one must consider that the marine site has the fourth dimension of time, because the disposed material takes longer or shorter periods of time to come to its initial rest on the bottom after having been discharged at or near the surface of the water. In practical terms, then, the release zone can be described easily in terms of coordinates of latitude and longitude (or Loran-C lines), but it is not within the confines of these dimensions or even of the three-dimensional unit that much of the dredged material comes to rest--even temporarily. Some of it, perhaps much of it, depending on the nature of the material, depth of water, and strength of current, will strike the bottom downcurrent of the release zone. We have come to call this extension of the release zone the **extended impact zone**. It is an understanding of this zone and the processes that account for its location and size relative to the release zone that is essential to the evaluation of the effects of disposal at sea.

As Pequegnat et al. (1978) have pointed out, the three conceptual components of the extended impact zone are its location in relation to the material being dumped, the hydrodynamics at and around the site, and its biodynamics or the influence that certain organisms are exerting on the finer materials while they are still falling in the water column. In truth, it is the extended impact zone that should be of greatest interest and concern to the manager of the marine environment, because its position and size in relation to human amenities will indicate to him whether a release zone should be moved in order to protect a valuable resource. The following paragraphs examine the oceanographic determinants of the extended impact zone.

Determinants of the extended impact zone

Location in relation to nature of disposed material. If dense material is dropped from a surface ship at a position that can be called the release point (Figure 1), the material will sink rapidly through the water column and come to rest on the bottom in a position more or less directly below the surface vessel. In this case the disposed material will have only a transient effect in its path through the water and a more permanent effect upon the bottom surface where it comes to rest. Reciprocally, the water column will have little effect on the direct passage of the material to the bottom. In this case the extended impact zone is little more than a vertical projection of the release zone. If, however, more typical fine sediment-type dredged material is disposed in the release zone, oceanographic and topographic factors will exert substantial effects on the path of the water column transit, and the material can come to rest upon the bottom in an area of variable size.

Hydrodynamics. If the material to be disposed includes a loose assortment of particle sizes ranging from pebbles through gravels, sands, silts, and clays, the extended impact zone is no longer a simple bottom projection of the release zone. Each particle tends to sink at a rate dependent upon its size (cross-sectional area) and its density relative to the densities of the water mass or masses through which it passes. Differential settling rates in the plume will result in a sorting of particles. But many of the particles may adhere to one another and behave as larger particles. The sinking of the entire mass may create a vertical current, which sucks the smaller and less dense particles downward for some distance. Eventually, however, the size and density of each particle will largely determine its own

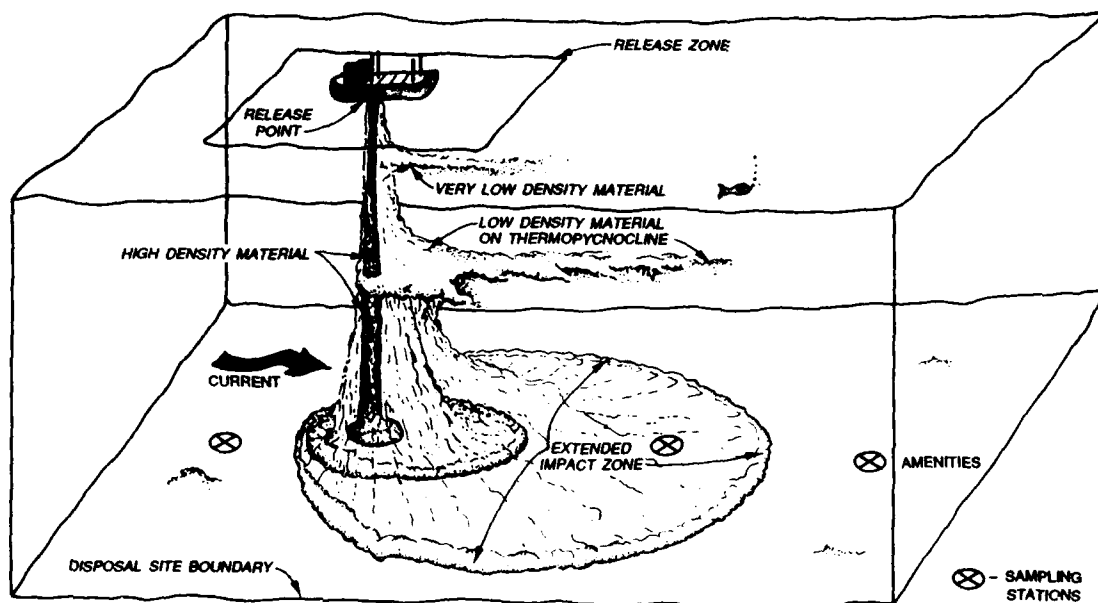


Figure 1. Schematic showing the extended impact zone (area on the bottom) and its probable relationship to the release zone of a dredged material disposal site during a hopper dredge discharge. The position of the release point, where the shipload is being discharged, can be changed by the District from time to time to obtain uniform distribution of sediments

rate of sinking. For a more complete description of the sinking of dredged material, see Pequegnat et al. (1978), Bokuniewicz et al. (1978), and Bokuniewicz and Gordon (1980). Clearly, depth becomes a determiner of the characteristics of the extended impact zone because it allows a longer time for the dynamics of the water column to transport the particles.

As a result of density sorting and water mass movement, dredged material composed of different size classes of particles will spread over large areas of sea bottom in a graded series, with the larger and denser materials settling closer to the release zone. Progressively finer particles will be distributed in a graded fan, extending for varying distances downcurrent as it forms the extended impact zone (Figure 1). Meanwhile, other factors may be affecting the sinking material (Brandsma and Divoky 1976, Pequegnat et al. 1978, Wright 1978).

Biodynamics. As the disposed material spreads out at the thermopycnocline and finally settles to the bottom, some of the finest particles will interact with certain living organisms in the water column. Many species of phytoplankton and zooplankton produce mucus or other gelatinous substances to which the particles would readily adhere and form clumps of appreciable size. Even marine bacteria may well be involved in this process. Such aggregations do drag many organisms to the bottom, but this effect is localized. This process clears up turbid water by hastening the removal of finer particulates from the water column. In addition, several zooplankton groups, such as copepod

crustaceans, feed by filtering large volumes of water with bristle-bearing appendages, which tends to concentrate finer materials into larger compact fecal pellets having faster sinking rates than the isolated particles.

Objectives of the Sampling Program

The sampling program of the field survey has been designed to fulfill two principal purposes. First, it is intended to yield data that are descriptive of the site environs and will thus characterize it sufficiently for preparation of an acceptable EA and/or EIS. Because historical data may be available for most parameters, care must be exercised in selecting those environmental variables that will be sampled and those that will not. The second purpose is to provide data that will be compatible with the potential monitoring program that may be carried out after final designation of the disposal site.

Site characterization and environmental documentation

Before either an interim or a new dredged material disposal site can receive final designation, adequate environmental documentation must be prepared, reviewed, and approved by the USEPA. Because today's documentation must emphasize a thorough analysis of alternatives and of the real and potential impacts resulting from dredged material disposal, the documentation should contain data on carefully selected oceanographic variables. Taken together, the values should provide not only a descriptive characterization of the site and its environs but also a functional understanding of the fate of the dredged material at that site.

It is not appropriate at this juncture to present details of the recommended sampling program, for that will be done in Parts VI and VII. Rather it is the authors' purpose here to establish the framework upon which the selection of variables to be surveyed and those not to be studied is based. The site surveys for interim or new sites are not scientific studies, i.e., gathering knowledge for its own sake; hence, if interpretive use cannot be made of data, it should not be included in the survey. In other words, survey work should be carried out in a scientific manner, but the range of variables must be limited. For example, it is doubtful that a short-term study of currents by means of fixed current meter arrays would yield useful data. In fact, it could mislead one in making certain decisions as to the fate of disposed material, as discussed in Basco, Bouma, and Dunlap (1974). If historical data of a longer term value are not available in the literature or technical reports, it may be possible at most sites to correlate water movements with long-term wind data for off-shore areas. A final point is simply that a single storm might result in more transport of sediments than a persistent current.

Most dredged material is sufficiently dense so as to fall rapidly to the bottom. Therefore, its transit time down the water column is too short to create appreciable impacts upon the pelagic biota. Moreover, since the water over the site will likely move out of the area in a short time, it seems that little useful information on impacts would be gained by this sampling. To sample at a given station after an interval of time would not ensure collecting impacted water and contained organisms. Both would have moved to a new undetermined position downstream. To ensure collecting impacted organisms after an interval of time would require employing some method of following the water mass. This is not to say that information on the pelagic biota is not a valuable component of site

characterization, because it is. But it is hoped that such information can be obtained in published literature or various technical reports issued to or by the CE District.

The main study emphasis should be on the benthic environment. It is there that any significant impacts will be registered, and it is there that sufficiently quantitative data can be collected. Where there are known to be significant seasonal fluctuations, these must be taken into account.

Establishing the sampling stations

The number and position of sampling stations established at and around a disposal site must be sufficient to accomplish the following:

- a. Characterize the site environment oceanographically.
- b. Predict the nature and intensity of impacts that dredged material might have on the site's environs.
- c. Identify resources of limited geographic distribution.
- d. Provide the basis for a monitoring program to test the validity of the predictions.

When an interim site receives final designation, it can be concluded that previous disposals have not been judged to be unacceptably adverse by those persons who prepared and approved the required environmental documentation. Therefore, it may be assumed that future impacts have been predicted to be no less acceptable. The monitoring program, if required, is intended to detect unacceptable adverse effects following disposal. In the case of designation of new sites, predictions that disposal of dredged material will not cause unacceptable adverse impacts must be documented.

In monitoring, sampling stations both inside and outside the area of net transport may be necessary. The number of sampling stations within a site will depend upon its size but normally ranges from two for the smallest site to six in the largest; however, site-specific conditions should be taken into account.

When critical areas or resources exist (Mathis and Payne 1984) in the vicinity of the disposal site (e.g., spawning grounds for commercially important species, beach or recreational area, etc.), then one or two sampling sites should be located between the disposal site and the critical area.

The rationale for locating the sampling sites as recommended and for taking only certain kinds of samples and leaving others out is based primarily upon oceanographic considerations. Since all but a few marine dredged material disposal sites are located on the continental shelf, the thrust of this guide will be concentrated there. Those persons who must deal with sites in deep, offshore waters may wish to consult appropriate sections of Pequegnat et al. (1978).

PART II: GROUPING OF SITES BY GEOGRAPHIC AND ENVIRONMENTAL CHARACTERISTICS

INTRODUCTION

In subsequent parts we shall discuss Corps Districts and their ocean sites for disposal of dredged material on the basis of such intrinsic characteristics as size, depths, and locations. Prior to doing that, however, it is deemed appropriate to give some consideration to the geographic, physical, and biological setting in which these sites are located. Both dredging and disposal activities are modified by general weather conditions and special biological features such as times of spawning or seasonal migrations of species of commercial or sporting importance. This is certainly not the place to discuss these issues in great detail, but it would be out of place to ignore them completely. Therefore, it is proposed to organize this part regionally, starting with the Northeast Coast and moving clockwise around the entire coast of the United States, including Alaska. In so doing, we will touch on weather, mention geomorphology, briefly describe current regimes, describe general aspects of the bottom, and finally note biologic parameters of importance, including fisheries.

ATLANTIC COAST

The Atlantic Coast of the United States is subdivided into three geomorphic regions (Northeast Coast, Middle Atlantic Bight, and South Atlantic Bight) and nine Corps Districts. During a flying trip from Maine to Florida along the coast, one could easily see some basis for this geomorphic separation. Moving south from the rocky shores of Maine one would pass over the drowned river mouths and broad shelves of the mid-Atlantic, which would narrow from Cape Hatteras to a mere strip of a shelf off Miami, only to broaden again as a wide carbonate shelf off Tampa and, after passing Cape San Blas, change to the broad muddy shelves of the Gulf States.

Geomorphology

Northeast Coast - New England Division

This geomorphic region extends southward from Cape Sable to Cape Cod and is commonly called the Gulf of Maine (Figure 2). This Gulf region derives its form from Georges Bank to the south and the Scotian Shelf to the north. The Gulf consists of flat-topped banks, low swells, and numerous basins with varying sill depths. These shallow basins (maximum depth 377 m) occupy 30 percent of the area of the Gulf. The deep areas of the basins are flat plains that contrast with undulating basin floors and the gently sloping basin sides. Between the basins, the floor of the Gulf of Maine is irregular due to outcrops of bedrock and concentrations of boulders of glacial origins. In fact, Pleistocene glacial and fluvial action was the primary force that shaped the present Gulf and furnished the wide variety of sedimentary types, ranging from clays to boulder tills, found there. However, terraces have been recognized at depths of 40 to 60 m around the submerged higher parts of the Gulf. These features have resulted from lower sea levels, perhaps as much as 120 m below today's level, during glacial times. The terraces are composed of deposits of shells, peat, and remains of terrestrial animals. Surficial sediments on the Gulf's shelf are primarily well-sorted sands composed of quartz, feldspar, glauconite, heavy minerals, and

rock fragments. The large basins have sediments that are high in silt and clay but have also a scattering of gravel and stones of various sizes. The continental slope is incised by numerous submarine canyons of which Corsair, Lydonia, Gilbert and Hydrographer canyons are the most prominent.

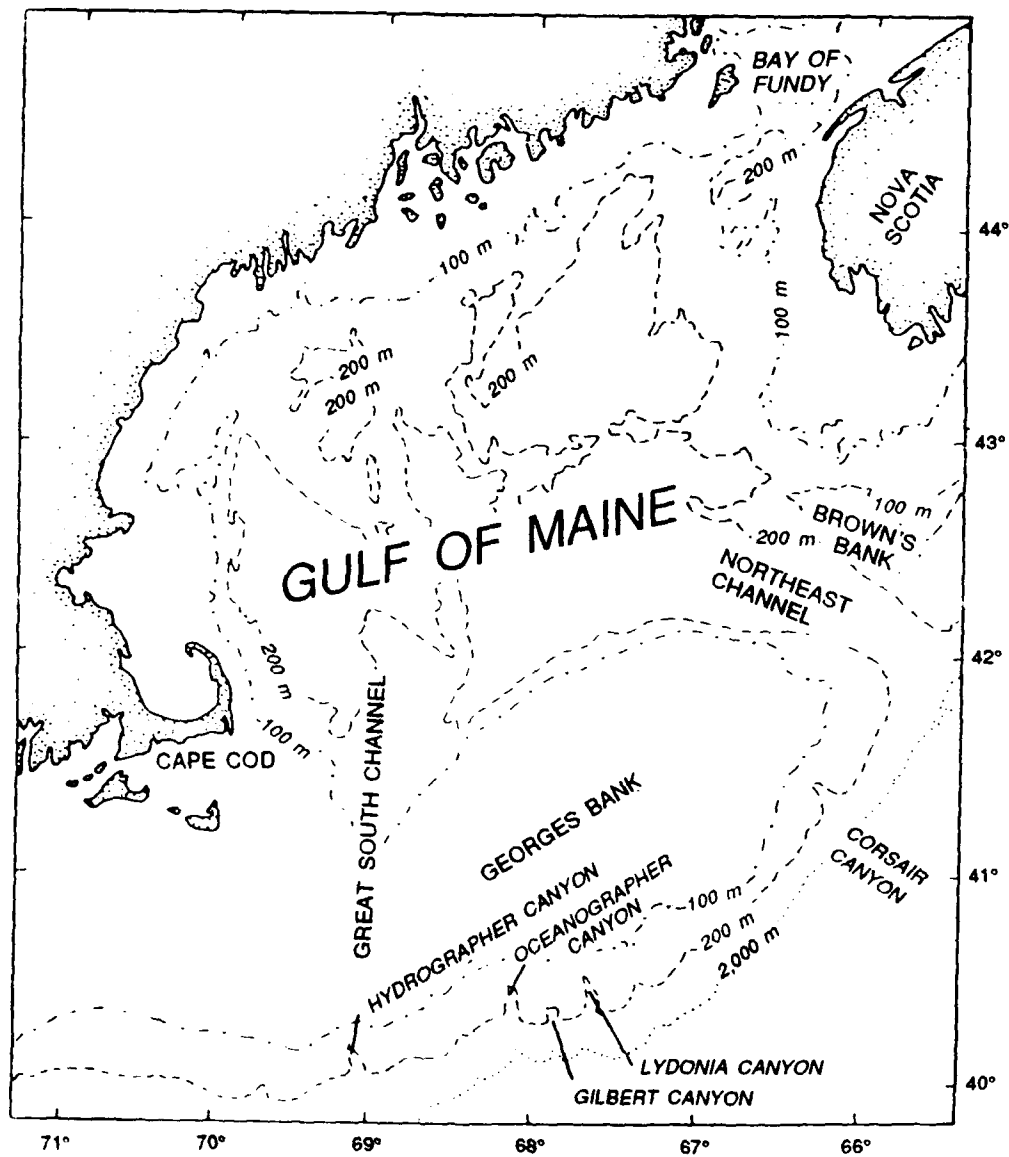


Figure 2. Geomorphology of Sector 1, Northeast Atlantic Coast (see Figure 9)

**Middle Atlantic Bight -
New York, Philadelphia, Norfolk
Districts; New England Division (part)**

This geomorphic region stretches from Great South Channel off Cape Cod to Cape Hatteras. The continental shelf of the region is a relatively smooth, seaward-dipping platform

that is disrupted by sand swells, channels, coral mounds, and terraces. The shelf area is 190 km wide south of New York City and narrows to a width of 23 km off Cape Hatteras. Just as occurred farther north, glacial activities here during the Pleistocene resulted in a series of erosional terraces paralleling the present shelf break, each terrace representing a stand-still of sea level. Redistribution of surficial relict sediments has partially buried or modified some, but not all, old stream channels that aerially developed during low sea level stands. Most of the Cape Cod-Hatteras shelf is covered by fine to medium quartz and feldspar sands that are occasionally interbedded with silt and clay layers. There are sand ridges that are up to 10 m high and extend for tens of kilometers. In shallow water, these sand ridges (or waves) can move shoreward, but in deep water they are essentially static. The southwesternmost part of the Cape Cod-Hatteras shelf supports a submerged, irregular calcareous reef made of algal and coral growths. These features are more common from Cape Hatteras southwestward.

South Atlantic Bight - Savannah, Charleston, Wilmington, and Jacksonville (Atlantic) Districts

This geomorphic region encompasses the coastal region of the United States from Cape Hatteras to Cape Canaveral. As noted above, four Corps Districts are located here. In this region the shelf is separated from the true continental slope by the Blake Plateau, the Florida-Hatteras Slope, and a small portion of the Florida Straits (Figure 3). Off Hatteras, the shelf break is at a depth of 55 m, but it increases to a depth of 70 m off Jacksonville and then decreases to a depth of less than 10 m in the vicinity of West Palm Beach. These variations in depth of the shelf break are due to sediment upbuilding off Cape Hatteras and to calcareous deposition off south Florida. The shelf in this Bight has no shelf channels, nor is it incised by heads of submarine canyons. There are, however, long sinuous shoals that project across the shelf from all of the capes (Cape Lookout, Cape Fear, etc.). The shelf also features low circular algal banks along the Carolina coast and the active and dead coral reefs south of West Palm Beach. Some of these are ancient reefs that border the shelf break in an almost unbroken line from Cape Hatteras to Miami. The sand cover on the shelf is well sorted and has a symmetrical grain-size distribution curve. South of Hatteras the sands contain a lot of calcium carbonate, although their texture is similar to the quartz and feldspar sands to the north. Most of the carbonate is biogenic and of local origin.

Oceanography/Meteorology

The general circulation of the north Atlantic Ocean is dominated by a clockwise gyre, which starts with the North Equatorial Current that is itself driven by the northeast trade winds. Off the coast of Florida the Florida Current from the Gulf of Mexico is joined by the Antilles Current from the south to form the Gulf Stream. The Gulf Stream veers away from the coast at Cape Hatteras and flows northeastward to the Grand Banks of Newfoundland. From there it becomes diffuse and is known as the North Atlantic Current (Figure 4).

Northeast Coast Region

The surface winds over the north Atlantic area generally come from a prevailing westerly direction throughout the year. There is, however, an overall shift to the northwest

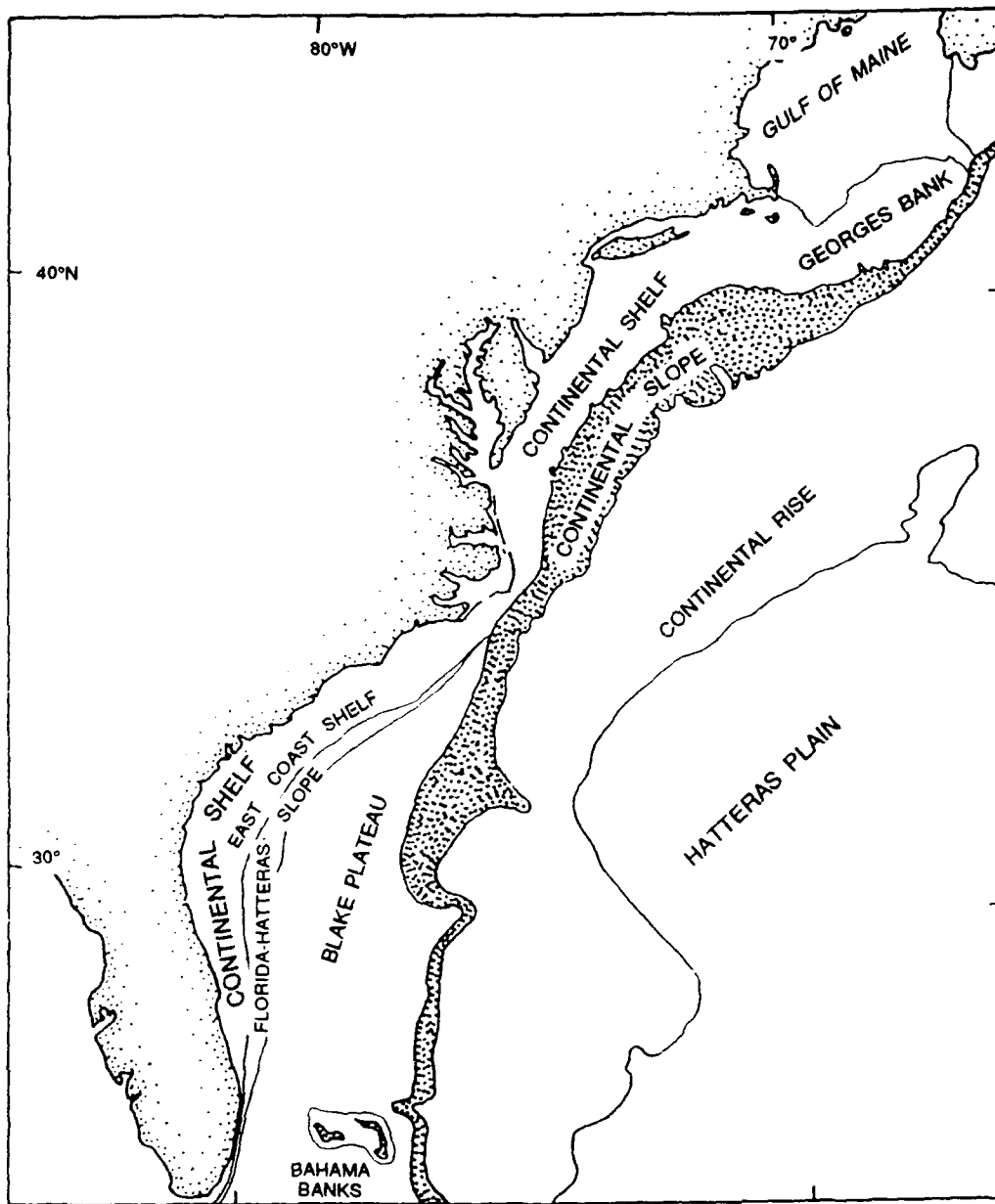


Figure 3. Physiographic provinces of the continental margin off the east coast of the United States (from Uchupi 1968)

during winter months and to the southwest during summer. Annual average onshore winds in the Northeast Coast region range from a high of 11.5 knots at Boston, MA, to a low of 7.3 knots at Brunswick, ME. Offshore wind conditions for the Boston Sea area show an annual mean of 14.2 knots from the southwest. The highest average velocities are observed in December-February, whereas the minimum average speeds are noted in July and August. Storms passing through the Northeast Coast region are of either the tropical or extratropical type. The low-pressure center of the extratropical storm enters the region from the west through the St. Lawrence Valley or New England, or from the offshore southwest

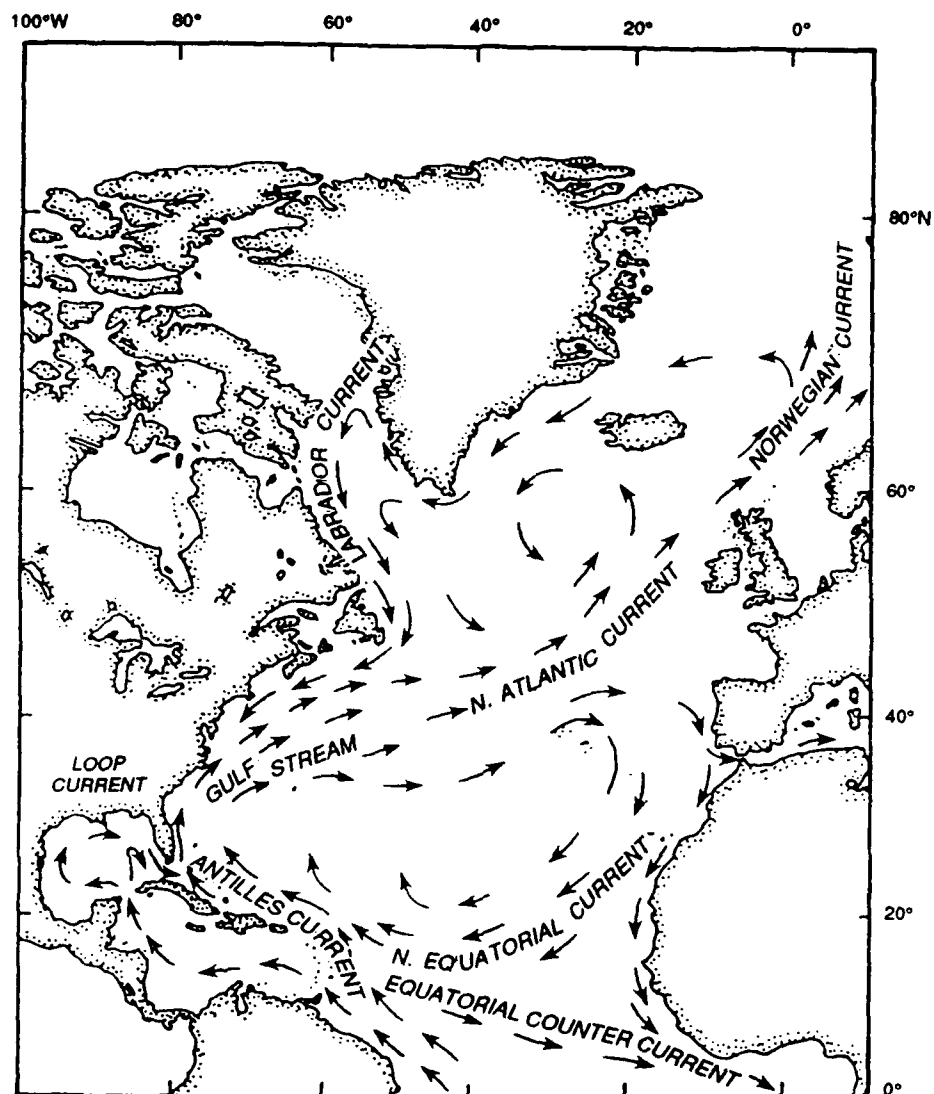


Figure 4. General circulation of the North Atlantic Ocean

quadrant. The tropical storms form over the warm waters of the Caribbean, Gulf of Mexico, or the Atlantic south of Cape Hatteras. The extratropical cyclones ("Nor'easters"), which move through the area from the southwest (with northeast winds) are usually quite severe, and are more frequent and intense between October and April. Tropical cyclones are most likely to move north into the area during late summer and autumn. They are usually more severe than extratropical storms.

Middle Atlantic Bight

Surface winds in this region are similar to those mentioned under the Northeast Coast section in that they tend to come from a prevailing westerly direction throughout the year. The position and intensity of the Bermuda Azores high-pressure system primarily control

the Bight's general surface wind pattern. During winter, the system is located far to the southeast, which causes major low-pressure storm systems to move through the mid-Atlantic states. In the spring, it begins to move northward, and by summer its northernmost position causes the entire eastern seaboard to experience frequent showers and thunderstorms. In the fall, the Bermuda-Azores high moves southward and eastward with the weather, gradually returning to its winter pattern. Most storms that occur throughout the mid-Atlantic region are either of the transcontinental or the tropical type. In general, the tropical storms occur in the fall or early winter, whereas the transcontinental ones occur primarily in the spring.

South Atlantic Bight

In winter the northern part of the sea area of this Bight (i.e., just south of Cape Hatteras) has predominant winds coming from the western quadrant. Along the Florida coast, however, easterly winds are predominant throughout the year. In the spring the northern part experiences winds from the west and the northeast, and in summer the Bermuda-Azores high causes southwesterly winds over the northern and middle portions of the coast. Recession of the high-pressure system in autumn results in an increase in frequency of northerly winds from the middle part of the region northward. Wind velocities are generally moderately light, averaging 7 to 10 knots over the year. The majority of the areas of the Bight experience calms from 15 to 20 percent of the time during the year. The Florida-Georgia part of the Bight is struck by hurricanes on the average of once every 2 years and by tropical storms somewhat more frequently. The frequency of occurrence of hurricanes or tropical storms affecting the coast reduces toward the northern part of the Bight.

Fishery Resources

For many years, the northwestern Atlantic Ocean has been considered to be one of the most highly productive fishing grounds in the world. The fishing industry of the northeastern United States is large and varied, operating both nearshore and considerable distances offshore, although the bulk of the catch comes from waters over the continental shelf. The northeast catches are landed in parts of New Jersey, New York, Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine.

Northeast Coast

Most of the major fishing areas of New England are banks or shoals, ranging in size from a few square kilometers to such plateaus as Browns and Georges Banks. Both the banks and the deep basins in the Gulf of Maine and north of Georges Bank are important to the fisheries. Of the nearly 200 species of fish that are known to exist in the region, less than 30 are of significant commercial value. The American lobster (*Homarus americanus*) and the hard clam (*Mercenaria mercenaria*) provide around 40 percent of the northeast US fishery production. Demersal fishes are also important to this fishery, led by cod, haddock, hakes, and flounders. Other shellfish and finfish of importance are the deep sea prawn, *Pandalus borealis*, and the ocean perch, scup, and pollock. Herring and menhaden dominate the pelagic catch in terms of poundage, but their monetary contribution is relatively small.

Middle Atlantic Bight

It is estimated that although 300 species of marine fishes occur in the mid-Atlantic Bight, only about 150 consistently occur on a yearly basis. As in the Northeast, almost the entire present commercial catch is made up of about 30 species. The relative importance of shell fisheries increases here over the Northeast. Hard clams, lobsters, sea scallops, surf clams, and oysters are the top fisheries, providing the greatest dollar value. The contribution of demersal finfish to the mid-Atlantic fishery production is reduced from that in the Northeast, and the importance of pelagic fisheries is increased by landings of such species as bluefish, bluefin tuna, seatrout, striped bass, and mackerel. Unique or highly productive biotopes, such as the productive banks and basins of the Northeast, are not common to the offshore mid-Atlantic area. However, such canyons as Hudson and Baltimore have unique faunal assemblages and provide important migratory pathways for fish and shellfish.

South Atlantic Bight and Peninsular Florida

The fisheries of the south Atlantic states rely heavily on shallow coastal and estuarine areas for the bulk of fishery production. South of Cape Hatteras, the commercial fisheries are almost totally limited to the area shoreward of the 80-m isobath. Shrimp constitute the most valuable fishery in the area, second only to the Gulf of Mexico. Other shellfish include crabs, oysters, scallops, and spiny lobster. Major finfish species include menhaden, flounder, spot, alewives, mullet, seatrout, sea bass, croaker, bluefish, and mackerel. The red snapper (*Lutjanus aya*) is found in the South Atlantic Bight around rock outcrops, reefs, and banks (20- to 200-m depth) between North Carolina and Florida. These important hard-bottom features include the *Lithothamnion* reef, 80- to 110-m isobaths from Cape Lookout to Cape Fear; the Black Rock reefs; and the hard-bottom communities and sport fishing grounds (100- to 200-m isobaths) off Capes Hatteras, Lookout, and Fear.

GULF OF MEXICO COAST

The Gulf of Mexico basin is one of the world's oldest ocean basins, having formed some 160 million years ago (Dietz and Holden 1970). It is also one of the deepest, if not the deepest, of the world's basins. Although its present deepest point measures about 3,850 m, it is estimated that the Sigsbee Abyssal Plain rests on a bed of sediments some 9 to 10 km thick. The major physiographic features of the Gulf are the continental shelf, which includes the West Florida Shelf, the Texas-Louisiana Shelf, East Mexico Shelf, and Campeche Shelf; the continental slope with steep escarpments; the Mississippi Fan; the continental rise; and the Sigsbee Abyssal Plain, or floor of the main basin.

Geomorphology

MAFLA Shelf - Jacksonville (Gulf of Mexico) and Mobile Districts

Technically this geomorphic region stretches from Cape San Blas to the Mississippi Delta, but as a matter of convenience we are including the western boundary of Peninsular Florida in the region. West Florida is essentially a huge carbonate bank characterized by a steep escarpment and great thicknesses of limestone and evaporites. The vast thicknesses developed because the upper surface remained at sea level while the base subsided. The

surface of the West Florida Shelf is one of low relief broken only by reef structures or shoreline features associated with former periods of lower sea level. The Florida Middle Ground, a living reef having an area of more than 750 km², is prominent on the shelf northwest of Tampa. Except for this evident feature, the western shelf is practically devoid of prominent relief. The unconsolidated sediments over the West Florida Shelf are thin and discontinuous. The vast majority of this sediment veneer is biogenous in origin and represents various stages of disintegration of coral, shells, and foraminifera tests. Scattered low outcrops of limestone and chert provide a substratum for coral and sponge growth.

The northeastern Gulf of Mexico is a region of structural and lithologic transition marked by DeSoto Canyon. The continental margin here attained its present form when outbuilding of terrigenous sediments from the northwest buried the old Cretaceous reef off northern Florida. A profound lithologic change occurs in the continental margins of the Gulf across a line extending from DeSoto Canyon on the northeast to Yucatan's Campeche Canyon in the southwest. Sediments east of the line are carbonate, whereas those to the west are largely elastics of terrigenous origin.

Texas-Louisiana Shelf - New Orleans and Galveston Districts

This region extends from the Mississippi Delta to the mouth of the Rio Grande River separating Texas from Mexico. The continental shelf in the northwestern Gulf ranges in width from about 100 km off the Rio Grande in Texas to more than 200 km south of the Texas-Louisiana boundary. Farther east, it is again narrowed by the Mississippi River delta, whose presently active lobe almost entirely crosses the shelf southeast of New Orleans to empty directly onto the continental slope. The break in slope that marks the outer edge of the shelf is difficult to define throughout much of this region, but on the average it is at a depth of about 120 m. Overall, the continental shelf of the northwest Gulf is a smooth, gently sloping sediment-covered plain, interrupted by occasional hills or banks. A feature peculiar to the shelf break in the northwest Gulf is a series of prominent banks or topographic highs rising abruptly from the generally smooth, sediment-covered bottom. These are related to salt dome structures. One of the more interesting ones is West Flower Garden. It and the similar East Flower Garden Bank are capped by what are considered to be the northernmost thriving tropical shallow water coral reefs in North America (Bright and Pequegnat 1974). The sediments on the shelf are products of marine transgression following the Wisconsin glaciation. These recent sediments are divisible primarily into near-shore sands and shell facies muds (i.e., silty clays and clayey silts); however, extensive areas are covered by alternating sands and muds. Most of the sand-sized particles in the outer shelf silty clays are foram tests or echinoid (sea urchin) fragments.

Oceanography/Meteorology

Although this guide is concerned primarily with the continental shelf and upper continental slope as suitable areas for dredged material disposal sites, it is necessary in connection with the oceanography of the shelf to note that circulation phenomena over the deep, open Gulf modify conditions on the shelf. Thus, the circulation in the eastern Gulf of Mexico is dominated by the Loop Current, whose relative northward penetration tends to vary seasonally. This current, which is an extension of one limb of the Gulf Stream, enters the Gulf from the Caribbean via Yucatan Channel at speeds up to 4 knots and exits

into the Atlantic via the Florida Straits, where it joins the Antilles Current to form the true Gulf Stream. This current and its branches drive the major surface circulation system of the Gulf and account for some of its biological features. It brings larvae, pelagic fishes, plant material (*Sargassum* and *Zostera*, etc.), and heat into the eastern Gulf in particular. But the Loop also has a major influence on the western part as well. When fully extended to the north, the Loop may cut off anticyclonic rings or gyres that slowly migrate into the western Gulf while spinning at substantial speeds. The Loop also entrains water on its northwestern edge that eventually spins off as a cyclonic ring that also moves westward.

The Mississippi River system also exerts an important effect on the shelf circulation of the Gulf. As the fresh water pours into the Gulf at the delta, it flows over the top of saline waters and creates a geostrophic current that because of the Coriolis effect turns to the right or westward. The river also discharges huge amounts of sediment into the Gulf each day. Some of it is transported due west where it falls to the bottom, creating rich fishing grounds, but more of it moves southwestward to the edge of the prograding delta and from time to time cascades down the slope onto the Mississippi Fan or onto the abysmal plain to the west, much as it did in the geologic past. Another factor that controls some aspects of the shelf circulation is the prevailing winds, which for most of the year are primarily from the southeast, except during the occurrences of the winter northers during the months of November through March. As mentioned above, the shelf flow is generally toward the west from the delta to Galveston, then continuing southwest parallel to shore and ultimately to the south along the western Gulf shelf. However, reversals in direction of flow along the southwest coast of Texas usually occur in summer, or during times when anticyclonic (clockwise) rings in the deep water of the western Gulf invade the shelf regions. Typical speeds of these longshore flows are ordinarily between 0.5 and 1.0 knot.

The climatic conditions of the Gulf region are broadly determined by the huge land mass lying to the north, its subtropical latitude, and the strength or intensity of semipermanent pressure ridges. At least two pressure ridges dominate weather conditions along the coast. The Bermuda high is centered over the Bermuda-Azores (clockwise circulation of the atmosphere) area of the Atlantic, and the other is the Mexican heat low (counterclockwise) centered over Texas during the warm months. Pressure changes associated with these ridges set up winds that prevail from an easterly direction--southeasterly winds predominating. During the winter, cold fronts invading the Gulf from the northwest produce strong winds with speeds ranging up to 60 knots. Abnormally high speed winds may occur during summer as tropical storms or hurricanes. Tropical storms (winds of 34 to 63 knots) and hurricanes (winds of 64 or more knots) are more frequent in the Gulf during August and September.

Fishery Resources

The Gulf fishery is economically dominated by shellfish, primarily shrimp, crabs, and oysters with smaller amounts of clams and scallops. The catch of finfish is dominated by the menhaden both in volume and value. Although the volume of the finfish catch greatly exceeds the catch of shellfish, the value of the shellfish catch is much higher. The main shrimp fishery includes the brown shrimp (*Penaeus aztecus*), the white shrimp (*Penaeus setiferus*), and the pink shrimp (*Penaeus duorarum*). Sea bobs (*Xiphopenaeus kroyeri*) and the deepwater royal red shrimp (*Hymenopenaeus robustus*) contribute a very small percentage to the shrimp catch. The dependence of the Gulf fishery on the coastal

environment is unparalleled, as about 97 percent of the total commercial fisheries catch for the Gulf is estuarine dependent, i.e., made up of species spending part or most of their lives in estuaries. Moreover, nearly all of the Gulf coast catch is made within a few miles of the coast, especially around or just east of the Mississippi Delta. The most valuable finfish in the Gulf fishery are menhaden, red snappers, mullet, spotted seatrout, croakers, groupers, pompano, Spanish mackerel, flounders, king mackerel, black drum, white seatrout, and sheepshead.

PACIFIC COAST

Geomorphology

Southern California Bight - Los Angeles District Northern California Shelf - San Francisco District

The geographic limits of the Southern California Bight extend from the California-Mexico border to Point Conception. The Northern California Shelf occupies the coast region on northward to Cape Mendocino. The continental margin of that region has a complex topography that differs markedly from that of the Atlantic seaboard or Gulf of Mexico.

The marginal continental shelf (sometimes called a continental borderland) of southern and central California is narrow (within the 200-m isobath), ranging from less than 2 km to about 23 km in width (average 6.5 km). However, from Point Conception northward it widens and is relatively flat (Figure 5). Islands, such as the Farallons of San Francisco, rise above the general level and many submarine canyons incise it below the general level (Figures 6 and 7). Sediments on the shelf tend to be shallow detrital sands containing various amounts of organic and authigenic sand-sized material. The outermost portion of the shelf and the adjacent slope reveal sandy silts that grade to fine silts seaward.

Northwest Shelf - San Francisco (part), Portland and Seattle Districts

The Northwest Shelf geomorphic region extends from Cape Mendocino, California, to Cape Flattery, Washington. This region contains three Corps Districts. The width of the shelf in this region is relatively narrow and generally steep in comparison with average shelf characteristics. Northward from Cape Mendocino the shelf tends to become increasingly wider (Figure 7). That portion off California averages less than 30 km, off Oregon about 40 km, and off Washington about 50 km. The widest regions of the shelf, 65 to 70 km, are Heceta Bank area off central Oregon and at the mouth of the Columbia River, whereas the narrowest segment, less than 10 km, is off Cape Mendocino. The shelf break in this region (i.e., where the continental slope begins) ranges between depths of 145 and 183 m. A number of submarine canyons incise the seaward edge of the continental shelf in this region. The major topographic features of the Oregon outer shelf consist of submerged banks, some of which have substantial measurements. For example, Heceta Bank northwest of Coos Bay is about 175 nautical miles long and stands 145 m off bottom to reach within 45 m of the surface. North of Heceta is Stonewall Bank, which is 115 nautical miles long with a relief of 35 m and a shoalest depth of 35 m. Surface sediments of the nearshore zone of the shelf in this geomorphic region are primarily sands consisting of detrital quartz and feldspar. This sand zone extends from shore to a water depth of about 90 m off the northern and central Oregon coast. Off Washington the sand zone forms a

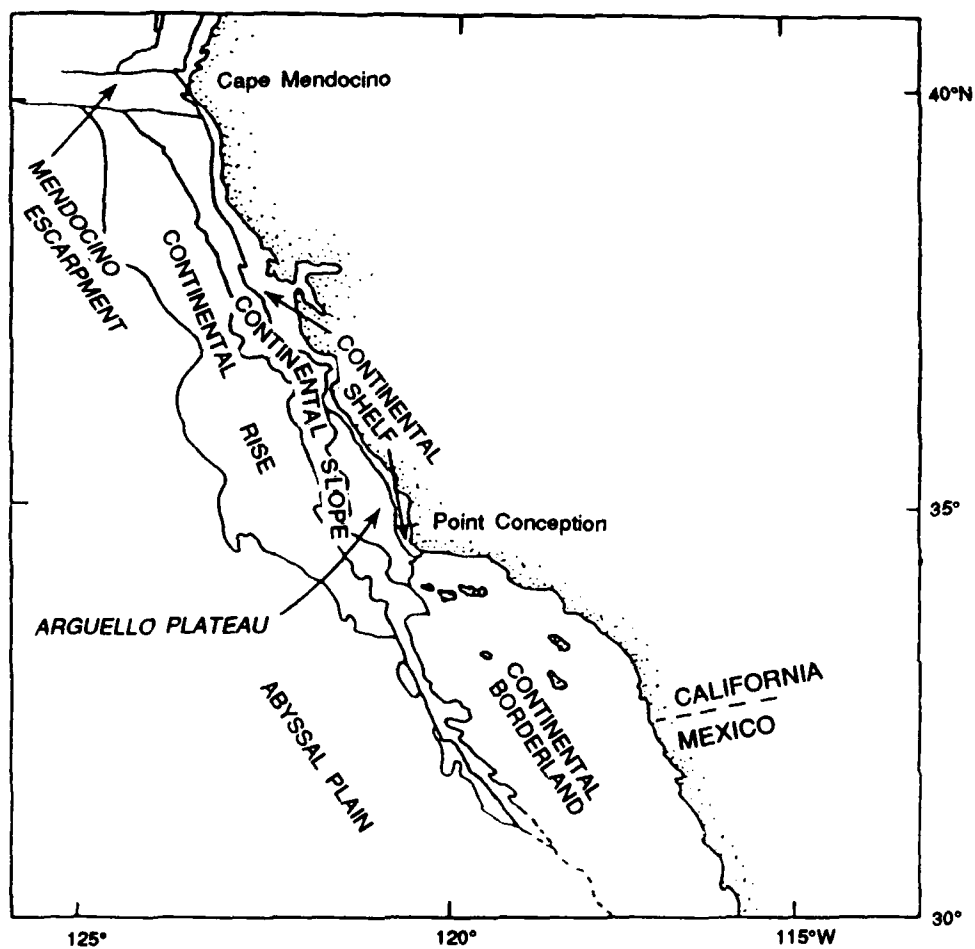
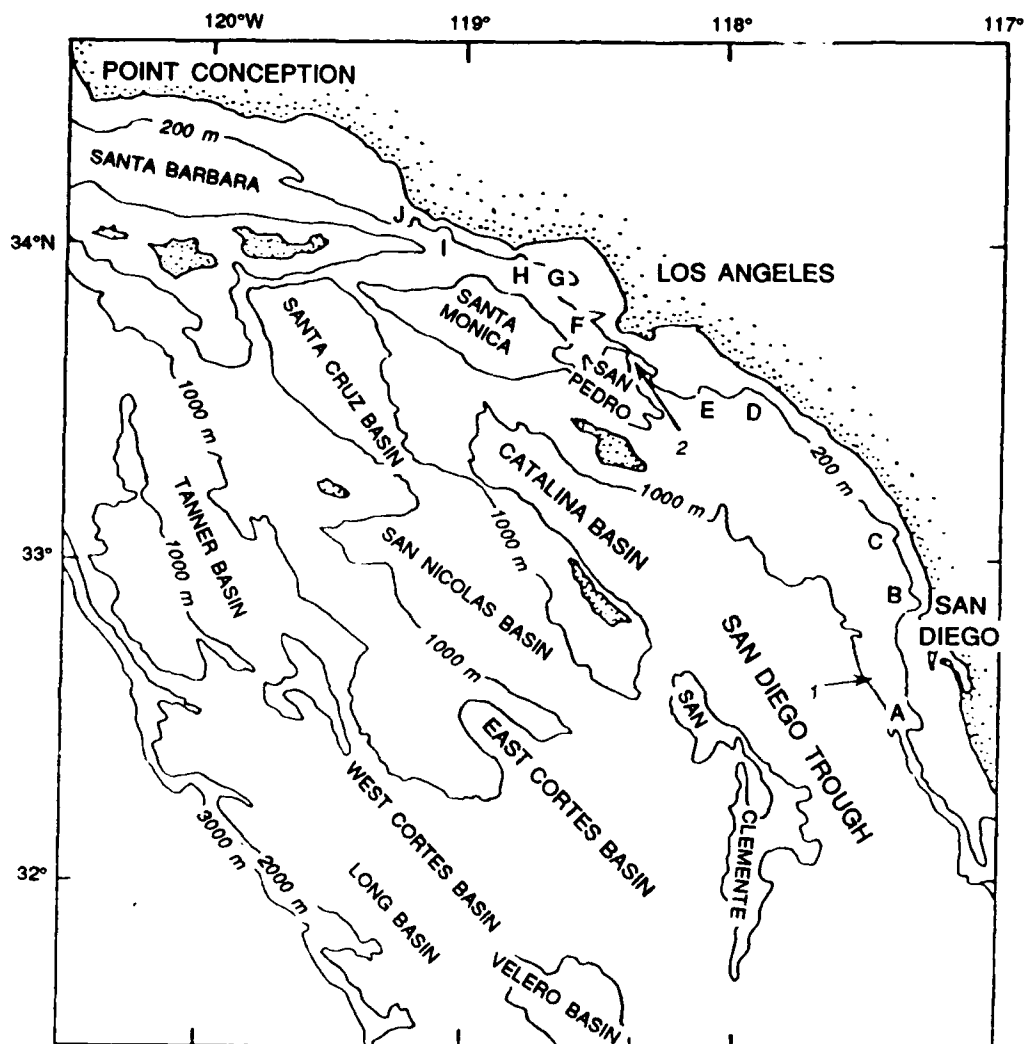


Figure 5. Physiographic provinces of the seafloor off California, Sectors 6 and 7 (after Uchupi and Emery 1963)



SUBMARINE CANYONS		ESCARPMENTS
A. CORONADO	F. REDONDO	1. CORONADO
B. LA JOLLA	G. SANTA MONICA	2. SAN PEDRO
C. CARLSBAD	H. DUME	
D. NEWPORT	I. MUGU	
E. SAN GABRIEL	J. HUENEME	

Figure 6. Continental borderlands off southern California showing basins, canyons, and escarpments (after Uchupi and Emery 1963)

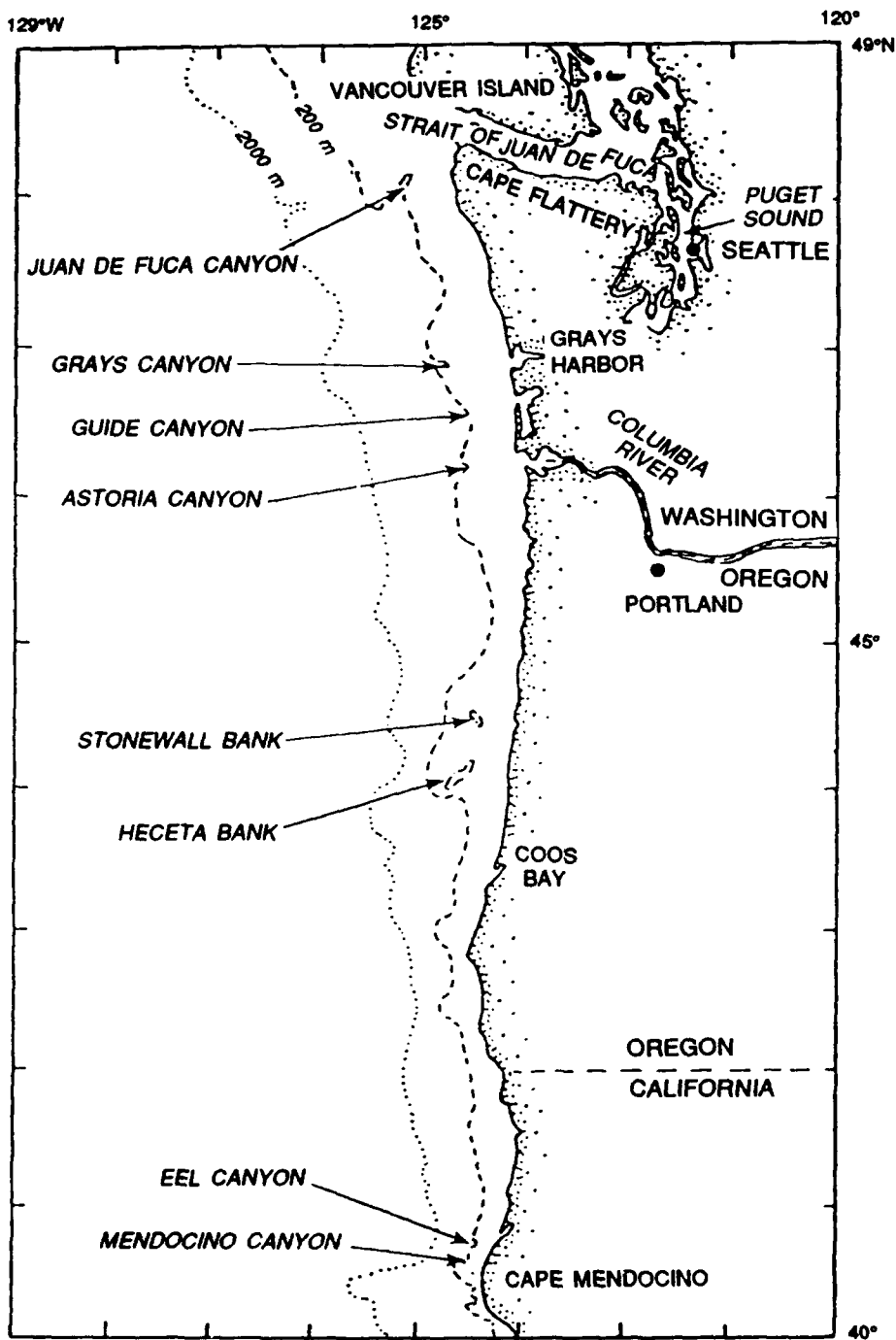


Figure 7. Relative positions of major submarine banks and canyons within Sector 8 (after Pequegnat et al. 1978)

narrower belt out to a depth of 50 m. Seaward of the sand zone the sediments consist of patches of mud and mixed sand, modern mud, and exposures of bare rock. Onshore-offshore transport rate of sand is greatest during the winter when longshore transport is north; in summer, longshore transport is to the south. Ripples in the bottom sediment have been found at water depths of 80 m in winter and 30 m in summer.

One of the outstanding geomorphic features of the region is Puget Sound, which is a narrow, deep, steep-walled inlet of the sea, formed by the submergence of the mountainous coast that was once the site of glacial activity. This fiord with numerous channels and branches extends 90 miles south from the Strait of Juan de Fuca to Olympia, WA. It has strong currents, up to 7 knots, which tend to follow the direction of the Sound's channels.

Oceanography/Meteorology

The Pacific coast oceanographic regime differs in certain important aspects from that of the Atlantic or Gulf coasts. Because of the relatively narrow continental shelf and the strong influence of regionally local wind conditions, the Pacific coastal area is subject to major upwelling events, which can produce associated marked changes in the circulation pattern on and near the shelf.

The circulation regime in this region is controlled by the weak eastern extension of the Kuroshio Current, which comes to be called the California Current when it impinges on the west coast of North America. The details of the flow near the Pacific coast are subject to the strong influence of local winds since, unlike the Atlantic coast or east Gulf, the mean currents are generally weak (less than 1 knot, as compared with 4 knots or more in the other regions). Upwelling does occur all along the Pacific coast, but less frequently to the north and south of the Oregon coast. In southern California several relatively weak currents are prevalent, viz. the Counter Current, which is part of the southern California Eddy, and the California Undercurrent, which is present below the Counter Current at depths between 150 and 800 m. Both currents move at speeds between 5 and 40 cm/sec. In the northwest shelf region, the important coastal flow is southward in the spring and summer and, with formation of the Davidson Current in the south, the flow is northward in winter.

Along the southern California coast the winds approach from the west or northwest as a result of the semipermanent east Pacific high-pressure area. It is most dominant in the warmer months of the year, May to September. From October through April, the high pressure diminishes and the winds are not as prevalent. Air movement from the land becomes more common. The Santa Ana condition is an offshore northeast desert wind that occurs primarily in the southern California coastal areas. These dry winds can be violent, being clocked at speeds over 50 knots. About once or twice a month a storm moves into northern California offshore waters. Some of these reach gale velocities and cause seas up to 12 ft. Such gales and rough seas are rare south of Los Angeles, but occur 1 to 4 days per month between Los Angeles and San Francisco. Tropical cyclones originate off the west coast of Mexico in summer and fall. The few that affect US coastal waters can be dangerous, occasionally generating winds of more than 120 knots.

Local winds of northern California, Oregon, and Washington vary from northwest to southwest throughout most of the year. However, in winter, strong winds, occasionally of

gale force, approach the Washington-Oregon coast from the southwest. Winter storms usually work their way from the central Pacific northward into the Gulf of Alaska or to the coast of British Columbia. Gales occur on about 3 to 5 days per winter month and may whip up seas to 20 ft or more up to 4 percent of the time. Summer storms move from west to east across the coast and last from 3 to 7 days and carry winds ranging from 10 to 20 knots with maxima of 50 to 55 knots.

Fishery Resources

Almost all of the sport and commercial fisheries of southern California consist of pelagic fish or such inshore predatory fish as halibut and rockfish. Bottom fish caught by trawling represent an insignificant fraction of the total catch. In northern California and the northwest United States, trawling and bottom longlining constitute a large portion of the fish landings. The commercial catch in southern California consists of pelagic species such as anchovy, Pacific mackerel, jack mackerel, and tunas. However, most of the tuna are caught in the tuna grounds off Mexico and Central America. Demersal species caught off central and northern California are such species as Dover and English sole, and petrale sole along with ocean pink shrimp and spot prawn (*Pandalus jordani* and *P. platyceros*).

The fisheries of the Northwest Shelf and Alaska are dominated by five species of Pacific salmon (*Oncorhynchus nerka*, *O. tshawytscha*, *O. gorbuscha*, *O. kisutch*, and *O. keta*), which make great oceanic migrations, and the herring (*Clupea pallasii*), which overwinters on the outer shelf and migrates into nearshore waters in the spring. Demersal finfish and shellfish commonly taken in the region are Pacific ocean perch, sabelfish, Alaska pollock, Pacific cod, Pacific halibut, flathead sole, and such shellfish as Dungeness crabs, tanner crabs, deepwater prawns, and the king crab.

ALASKA - ALASKA DISTRICT

Geomorphology

The Gulf of Alaska geomorphic region is characterized by a smooth, southwest sloping floor that contours roughly parallel to the western coast of Canada and southeastern Alaska. Many seamounts in the Gulf rise above the plain, some with a relief of more than 3,000 m. The continental shelf is wide to the south but narrows toward the Aleutian Islands. It is 275 km wide in the vicinity of Kodiak Island but is only 75 km wide off the tip of the Alaska Peninsula and only 20 km near the Aleutians (Figure 8).

Oceanography/Meteorology

The general circulation in the Gulf of Alaska can be described as the counterclockwise Alaska gyre, which is considered to be composed of two flows, the Alaska Current and the Subarctic Current. The Alaska Current is found in the northern and western parts of the Gulf of Alaska where it flows east to west parallel to shore and persists up to 200 miles or more from the shore. The Subarctic Current is found farther offshore where it flows to the east. Current speeds range from about 1 knot off Kodiak Island to a range of 0.1 to 0.5 knot over the rest of the area.

Gales with winds greater than 33 knots blow 10 to 20 percent of the time and are most likely in November and December. Wind speeds average 10 to 20 knots during the winter,

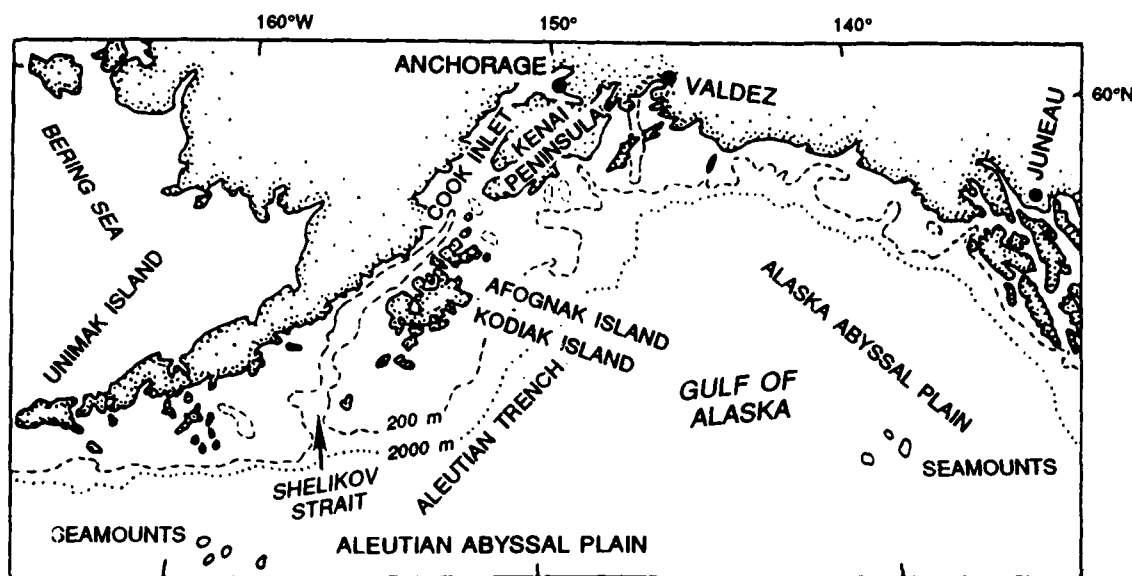


Figure 8. Gulf of Alaska geomorphic features (after Fullard and Darby 1970)

but "williwaw" winds from the mountains have reached as much as 74 knots, and gusts of 60 knots or greater occur almost monthly during the winter. Shifts from winter to summer are subtle--storms and strong winds still come, but gales are less frequent. For example, July has gales less than 1 percent of the time, but September has them 5 to 10 percent of the time, and November and December up to 20 percent of the time.

Fishery Resources

Fishery resources of the Gulf of Alaska were described under the Northwest Shelf section.

HONOLULU DISTRICT, PACIFIC OCEAN DIVISION

Geomorphology

The islands in the Pacific under jurisdiction of the Honolulu District include the State of Hawaii, the Territories of Guam and American Samoa, the commonwealth of the Northern Mariana Islands, and the Republic of Palau, including other smaller islands such as Johnston Island and Palmyra Island. These islands are scattered throughout the central and western Pacific Basin in both northern and southern hemispheres. These island groups are essentially mountainous peaks rising from the ocean floor and consist of volcanic peaks in Hawaii and a mixture of volcanic and limestone high islands and of low-lying coralline atolls in American Samoa. The insular shelves surrounding the islands are narrow, and deep waters can be reached in relative short distances from the edge of these shelves. Of these groups of islands only Hawaii is volcanically active. The Mariana Islands, consisting of the Territory of Guam and the commonwealth of the Northern Mariana Islands, are located near the Marianas Trench.

Oceanography/Meteorology

Surface currents flowing around and between these island groups are strongly influenced by prevailing winds, tidal cycles, and deep ocean bathymetry. Hurricanes and typhoons normally occur during the months of June and July, but occur almost year-round with the most devastating events occurring during November through January. Significant hurricane events in Hawaii and American Samoa are usually rare, with most frequent events being major tropical storms.

Fishery Resources

Fishery resources in the Pacific Islands are principally located in the nearshore, shallow reef environment areas of the insular shelves. The richest fishing grounds tend to be located around banks within 125 m of water where snappers and bass are principally caught. Deep ocean longlining, seining and trolling for tunas and marlins, as well as trawling activities, are usually located around offshore seamounts. Foreign fisheries using ports located throughout the island groups comprise the principal fishing industry, while local fisheries tend to be rather small enterprises catering to local consumption. Some fish caught by local fishermen in nearshore waters, particularly tunas, are shipped to markets on other islands or to Japan for the fresh fish trade. Demersal trawling on the ocean floor is not common, but there is increasing interest in deep ocean mining in the Pacific.

CARIBBEAN TERRITORIES OF US VIRGIN ISLANDS AND PUERTO RICO - JACKSONVILLE DISTRICT

Geomorphology

Puerto Rico together with St. Croix, St. Thomas, and St. John of the Virgin Islands comprise territories of the United States within the Caribbean Sea. All but St. Croix rise from the same bank, the Puerto Rico-Virgin Island Platform, but are separated by water depths of up to 30 m. St. Croix is separated from the Platform by a fault valley that is about 4,600 m deep. The insular shelf is extremely narrow along the north shore of both Puerto Rico and St. Croix with the 200-m isobath being little more than 3 km from shore in most places. Even on the south side the shelf is usually less than 17 km wide out the 200-m isobath.

Oceanography/Meteorology

Puerto Rico and the US Virgin Islands are situated in the trade wind belt and have very steady winds from the east and east-northeast. These winds drive the main currents of the surface circulation in the region around the Islands. The main current is formed by a joining of the North Equatorial Current with the Guiana Current. That part of this great current that flows through the Caribbean Sea is called the Caribbean Current, whereas the part that flows to the north side of the Caribbean Island chain is called the Antilles Current. The latter is one limb of the Gulf Stream which is formed when the Antilles Current joins the Loop Current after it exits the Gulf of Mexico via the Florida Straits. Although the major flow is to the west along the shelf edge, there may be a reversal to the east when the trade winds are calm. During December to February, trade winds reach their primary maximum in speed. The primary minimum in normal wind speed occurs in the period from September to November. Since the islands lie in the path of tropical storms

and hurricanes, winds of extreme force may strike at any time of year but are most likely between July and November. Storm winds up to and exceeding 142 knots have been recorded on Puerto Rico. A devastating hurricane struck St. Croix and Puerto Rico in September of 1989.

Fishery Resources

Fish pots set in reef areas up to depths of 60 m provide catches of such bottom-dwelling species as groupers, snappers, parrotfish, grunts, wrasses, and spiny lobster. Seagrass areas are inhabited by the large gastropod mollusc *Strombus gigas*, which is severely overfished. Trawling for fish is limited by the narrow shelf and steep slope characteristic of all of the islands. Trolling yields several species, including Spanish mackerel, king mackerel, and others.

PART III: GROUPING OF SITES BY PHYSICAL CHARACTERISTICS

INTRODUCTION

Over the years at least 130 ocean sites for the disposal of dredged materials have been used by the coastal Districts of the US Army Corps of Engineers. For the most part, use of these sites appears not to have unacceptably degraded the marine environment or endangered human health. It would seem wise therefore to obtain a clear conception of the general nature of these sites that have served our needs effectively at the time one is designing an oceanographic survey plan for locating and designating new sites or for those interim sites for which an Environmental Impact Statement remains to be prepared. Although the number of ocean sites has been reduced to a total of 108, the need for new sites still exists. Also, on occasion the CE has lost the use of dredged material sites because disposal had created an environment attractive to a fishery species. For instance, some 75 years of disposal of dredged material and rubble at the Eatons Neck site in Long Island Sound had transformed a sandy, sloping seabed that edged upon a rock and pebbly area to an irregular bottom with variable mounds composed of fine-grained material plus debris and even some car wrecks. This became a favored lobstering area because the pebbly area served as a lobster spawning ground and mature lobsters used the site as a refuge and feeding habitat. The CE moved the site under pressure exerted by local fishermen and interested members of Congress.

CORPS DISTRICTS

Eighteen Districts of the CE (in nine sectors) are discussed in this manual (Figure 9). Sixteen of these are located in coastal regions of the contiguous 48 states and one each is located in Alaska and Hawaii. Nine of the 16 are located on the East Coast, three on the Gulf Coast, and four on the West Coast. The Gulf Coast actually includes four, since the Jacksonville District has operations on both the Atlantic Ocean and the Gulf of Mexico. The disparity in numbers between the East and West Coasts simply reflects the fact that there are many more estuaries and thus harbors that need dredging on the East Coast than on the West Coast. Even so, the CE does much more maintenance dredging in the Gulf than on the other coasts combined and in Alaska and the South Pacific as well. Ordinarily, the New Orleans District, which is located on the Mississippi River, dredges more sediment than the Galveston and Mobile Districts combined, largely in order to keep the river passes of the delta open to ships of commerce. This is not surprising in view of the fact that in an average year the Mississippi River can transport as much as one million cubic yards of sediment to the delta in a single day. Although the New Orleans District has 15 ocean disposal sites, much of the maintenance dredged material is placed in Mississippi River sites such as the one near Southwest Pass.

SITE CHARACTERISTICS SUMMARY

The features discussed here for describing the existing ocean dredged material sites include depth, size, and distance from the shoreline. These features have been compiled in Table 1 for most of the present disposal sites used by the coastal Corps Districts. Depth is shown in meters and has been divided into three categories: shallow (1-20 m), intermediate depths (21-99 m), and deep sites (>100 m). Two thirds of the sites are shallow with depths between 2 and 20 m, and the rest are equally divided between those having

moderate (21-90 m) or deep (>100 m) depths. About half of the sites are of medium size (0.5-3.9 square nautical miles), a little over a third are small (<0.5 square nautical miles), and the remainder have areas over 4 square nautical miles. Again, 52 percent of the sites lie in the Territorial Sea (3 nautical miles or less from the baseline), 44 percent are located in the Contiguous Zone, and the remainder lie beyond the zone. At this writing, the typical site averages around 2 square nautical miles in size and is located less than 12 nautical miles offshore in water less than 20 m deep (see Tables 2-4).

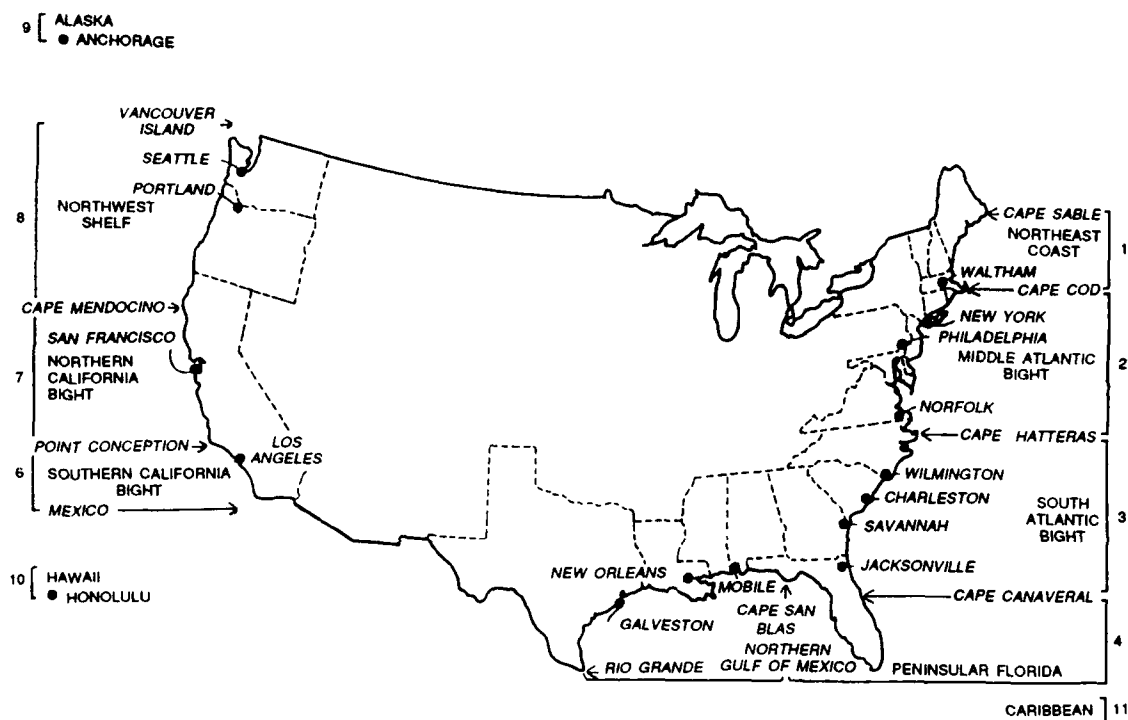


Figure 9. Sectors of the United States in relation to Corps Districts

Table 1
Characteristics of Ocean Dredged Material Disposal Sites

CE District Sites	Depth*			Size**			Distance†		
	SH	INT	DP	SM	MED	LG	NEAR	INT	DIS
Atlantic Coast									
New England - 3		3		1	2		1	2	
New York - 6	5	1		1	5		5	1	
Philadelphia - 3	3			3			3		
Norfolk - 1	1					1		1	
Wilmington - 2	2				1	1	2		
Charleston - 4	4				3	1		4	
Savannah - 2	2				2			2	
Jacksonville (Atlantic) - 8	5	1	2	1	7		2	6	
Caribbean - 5			5		5		3	2	
Gulf Coast									
Jacksonville (Gulf) - 2	1	1		1		1		1	1
Mobile - 9	8	1		1	5	3	5	4	
New Orleans - 15	15			5	6	4	11	3	1
Galveston - 10	10			4	2	4	5	3	2
Pacific Ocean									
South Pacific - 6			6		6			6	
Pacific Coast									
Los Angeles - 5		1	4		5			5	
San Francisco - 4	1	2	1	3	1		2	2	
Portland - 18	5	13		18			15	3	
Seattle - 3	1	2		1	2			3	
Alaska - 2	2	—	—	2	—	—	2	—	—
Total = 108	65	25	18	41	52	15	56	48	4

* SH = shallow (60%); INT = intermediate (23%); DP = deep (17%).

** SM = small (38%); MED = medium (48%); LG = large (14%).

† NEAR = nearshore (52%); INT = intermediate (44%); DIS = distant (4%).

Table 2
Corps District Analysis, Depth Distribution
of Ocean Disposal Sites for Dredged Material

<u>CE Districts</u>	<u>Depth at Center of Disposal site, m</u>		
	<u>1-20</u>	<u>21-99</u>	<u>>100</u>
New Orleans	15		
Galveston	10		
Mobile	8	1	
Charleston	4		
Philadelphia	3		
Savannah	2		
Wilmington	2		
Alaska	2		
Norfolk	1		
Portland	5	13	
New York	5	1	
Jacksonville (Atlantic)	5	1	2
Jacksonville (Gulf)	1	1	
San Francisco	1	2	1
Seattle	1	2	
New England		3	
Los Angeles		1	4
South Pacific			6
Caribbean			5
	<u>65</u>	<u>25</u>	<u>18</u>
	60%	23%	17%

Table 3
Corps District Analysis, Size Distribution
of Ocean Disposal Sites for Dredged Material

<u>CE Districts</u>	<u>Area of Disposal, square nautical miles</u>		
	<u><0.5</u>	<u>>0.5-3.9</u>	<u>>4.0</u>
Portland	18		
Philadelphia	3		
Alaska	2		
Los Angeles		5	1
Norfolk			
Savannah		2	
Caribbean		5	
South Pacific		6	
Seattle	1	2	
New Orleans	5	6	4
Jacksonville (Atlantic)	1	7	
Mobile	1	5	3
New York	1	5	
Charleston		3	1
Galveston	4	2	4
New England	1	2	
Wilmington		1	1
San Francisco	3	1	
Jacksonville (Gulf)	<u>1</u>	<u>1</u>	<u>1</u>
	41	52	15
	38%	48%	14%

Table 4
Corps District Analysis, Distance from Shore Distribution
of Ocean Disposal Sites for Dredged Material

<u>CE Districts</u>	<u>Distance from Nearest Shore, nautical miles</u>		
	<u>0.3</u>	<u>>3-12</u>	<u>>12</u>
Portland	15	3	
Philadelphia	3		
Wilmington	2		
Alaska	2		
Los Angeles		5	
South Pacific		6	
Charleston		4	
Savannah		2	
Norfolk		1	
Jacksonville (Gulf)		1	1
New Orleans	11	3	1
Galveston	5	3	2
New York	5	1	
Caribbean	3	2	
Jacksonville (Atlantic)	2	6	
Mobile	5	4	
San Francisco	2	2	
New England	1	2	
Seattle		3	
	<u>56</u>	<u>48</u>	<u>4</u>
	52%	44%	4%

PART IV: ANALYSIS OF SITES BY DISTRICT

INTRODUCTION

The distribution among Corps Districts of the present 108 dredged material sites and specific details about their characteristics are discussed in this part. From past experience, we are aware that these data are used by District Engineers to compare their maintenance dredging problems and costs with those of other Districts. This information should also provide some guidelines to the CE in the selection of new sites, and to the USEPA in evaluating the acceptability of new sites under consideration for designation.

The 108 sites presently designated or under active study for designation between 1988 and 1991 are, as noted above, distributed more or less according to need among the Districts. There may appear to be discrepancies in the number of Districts under discussion in this part between the text and tabular presentations. The reason for this is simply that although the Baltimore District might be considered coastal, since it is located on Chesapeake Bay, it does not have any ocean dredged material sites; hence, it is not discussed nor included in the tables. Another reason is dependent on the fact that the Jacksonville District has jurisdiction over Atlantic, Gulf, and Caribbean sites, just as the Hawaii District is responsible for dredged material sites in the Hawaiian Islands, Pago Pago in American Samoa, Apra Harbor in Guam, and Saipan in the Mariana Islands. In the following discussion the Districts have been grouped according to the following categories: Atlantic Coast; Caribbean; Gulf Coast; Pacific Coast, including Alaska; and Pacific Ocean.

ATLANTIC COAST

The eight Corps Districts along the eastern seaboard, exclusive of the Baltimore District, have jurisdiction over 28 ocean dredged material sites. These are discussed under the proper District name, except of course New England, which is a Division.

New England Division

Only three of the eight sites utilized for the disposal of dredged material by the Division are discussed here. This is because the remaining sites are located in Long Island Sound, which is considered to be an estuary and thus the sites are not covered by Section 103 of the Ocean Dumping Act but rather by Section 404 of the Clean Water Act.

Geomorphically, the coastal domain of the New England Division stretches from Cape Sable, Maine, to western Long Island Sound (Figures 2 and 10). This area is characterized by rocky glaciated shoreland and submarine topography, making oceanographic bottom sampling difficult. Moreover, it has deep basins and broad productive banks of steep slopes, and a very wide shelf. Surficial sediments on the shelf region are primarily well-sorted sands composed largely of quartz and feldspar plus some glauconite, heavy minerals, and rock fragments. The large basins of the Gulf of Maine have sediments that are high in silt and clays, the latter of which may be useful (depending on the type of clay) in sequestering heavy metals and organochlorine compounds.

The ocean dredged material sites utilized by the Division have an average depth of 52 m, and none are deeper than 100 m. They have an average area of 1.33 square nautical miles, and are located an average of 6.1 nautical miles offshore (Table 5). Both the banks

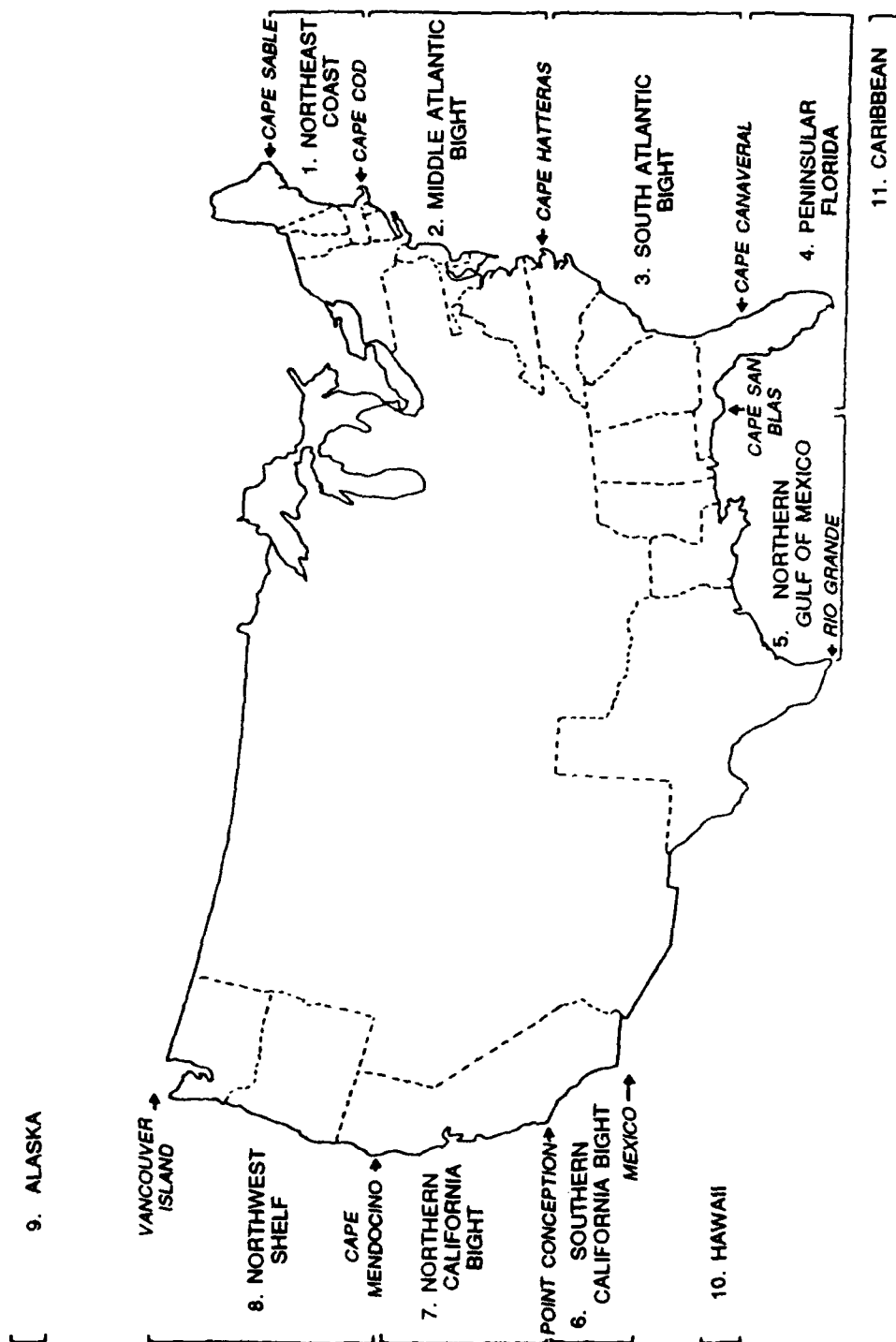


Figure 10. Sectors of the United States showing the related geomorphic regions

and basins are important to fisheries. The four most important species based on their dollar value are the American lobster (*Homarus americanus*), the Caridean shrimp (*Pandalus borealis*), the soft-shell clam (*Mya arenaria*), and the ocean perch (*Sebastes marinus*).

Table 5
Characteristics of New England Division Disposal Sites

Site	Depth m	Area n mi ²	Distance n mi
Portland, Maine	34	0.8	4.5
Cape Arundel, Maine	30	0.05	2.8
Massachusetts Disposal Site	93	3.14	11.0

During the last 20 or so years, the New England Division has dredged an annual average of 1 million cu yd, including both new work and maintenance dredging. The Division disposes of 10 percent of the material on land, 10 percent in estuaries (e.g., Long Island Sound), and 80 percent in the relatively shallow sites discussed here (Pequegnat 1986).

New York District

The average ocean disposal site used by the New York District is 12.3 m deep, has an area of 1.05 square nautical miles, and is located 1.43 nautical miles offshore. The six sites are listed in Table 6.

Table 6
Characteristics of New York District Disposal Sites

Site	Depth m	Area n mi ²	Distance n mi
Fire Island	7	1.1	0.3
Jones Inlet	9	1.2	0.4
East Rockaway	8	0.8	0.6
Rockaway Inlet	10	0.4	1.0
Mud Dump	27	2.2	5.8
Shark River	13	0.6	0.5

The New York District lies in the northern part of the Middle Atlantic Bight, which encompasses the coast from Cape Cod to Cape Hatteras. This bight is characterized by lowland streams, coastal marshes, and a trend southward toward muddy bottoms. The shelf is smooth and wide, and the continental slope is dissected by many canyons. Most of the shelf from Cape Cod to Hatteras is mantled by fine to medium quartz and feldspar sands that are frequently interbedded with silt and clay layers (Pequegnat et al. 1978).

In the Middle Atlantic Bight the relative importance of shell fisheries is greater than in the northeast. Hard clams, lobsters, surf clams, and oysters continue to provide the greatest dollar value. The contribution of demersal finfish to the F ight production lags

behind that found in New England, and the pelagic fishery increases in importance with landings of bluefish, bluefin tuna, seatrout, striped bass, and mackerel.

The New York District produces between 5 and 6 million cu yd of dredged material annually. About 8 percent is disposed on land, 2 percent in the estuary, and 90 percent in the New York Bight at the Mud Dump (Pequegnat 1986) some 6 miles off the New Jersey coast in the New York Bight. It has been in use since 1914 even though it has an area of only approximately 2.2 square nautical miles. In 1983 it was estimated that its remaining capacity was about 100 million cu yd. Thus, in June 1984, USEPA ruled that the Mud Dump would be closed permanently when 100 million cu yd had been disposed there from 4 June 1984 onward.

Philadelphia District

The three dredged material sites used by the Philadelphia District are shallow in depth (averaging 6.3 m), very small (averaging only 0.036 square nautical mile), and are very near shore (averaging only 0.6 nautical mile offshore). All of these characteristics are substantially smaller than those of any other Corps District on the Atlantic seaboard (Table 7). In this region of the Middle-Atlantic Bight, almost the entire shelf is covered by subarkosic sand ranging in size from medium to very fine and rarely containing more than a small percentage of silt or clay (Milliman, Pilkey, and Ross 1972). Gravel or sandy gravel deposits are located in various areas on the shelf, with the largest of them lying south of the Hudson Shelf Valley (Schlee 1973).

Table 7
Characteristics of Philadelphia District
Disposal Sites

Site	Depth m	Area n mi ²	Distance n mi
Manasquan Inlet	7	0.03	0.3
Absecon Inlet	6	0.04	0.8
Cold Spring Inlet	6	0.04	0.7

Norfolk District

Norfolk District uses only one ocean dredged material disposal site, Dam Neck, which has an area of 8 square nautical miles and lies 3.3 nautical miles offshore in 12 m of water. This District is the northernmost in the South Atlantic Bight, which stretches from Cape Hatteras to Cape Canaveral, although Cape Hatteras is in the Wilmington District. The Bight is characterized by extensive marshes, cypress swamps, and muddy bottoms. It is estimated that the Norfolk District dredged about 5.5 million cu yd in 1987 of which about 1.5 million cu yd was placed in Dam Neck and 2 million in Craney Island (personal communication, Gene Whitehurst, Norfolk District, 1989).

Table 8
Characteristics of the Norfolk District
Ocean Disposal Site

<u>Site</u>	<u>Depth</u> <u>m</u>	<u>Area</u> <u>n mi²</u>	<u>Distance</u> <u>n mi</u>
Dam Neck	12	8.0	3.3

Wilmington District

The two ocean dredged material sites used by the Wilmington District are located an average of 1.25 nautical miles offshore (Territorial Sea) where the water is only 13 m deep. There is a considerable difference in the size of the sites, with the Wilmington Harbor site being the larger (Table 9). This is because it receives the maintenance material from Wilmington Harbor, which has much greater maintenance needs than Morehead City Harbor.

Table 9
Characteristics of Wilmington District
Ocean Disposal Sites

<u>Site</u>	<u>Depth</u> <u>m</u>	<u>Area</u> <u>n mi²</u>	<u>Distance</u> <u>n mi</u>
Morehead City Harbor	13	8.0	3.0
Wilmington Harbor	13	2.3	3.0

Surficial sediments on the inner shelf between Cape Lookout and Cape Fear are predominantly sand with a few isolated calcareous banks and a large patch of gravelly sand that runs east-southeast of Smith Island (US Department of the Interior, Bureau of Land Management 1977). The sands contain varying amounts of shell debris to which many types of organic compounds have been added. Both of the Wilmington District disposal sites are positioned over areas of sandy bottom that is clear of the scattered hard banks.

Charleston District

The four ocean dredged material disposal sites of this District range in size from 0.8 to 11.8 square nautical miles (average 3.7), and are positioned an average of 5.7 nautical miles offshore (all in the Contiguous Zone) where the water averages about 10 m in depth (Table 10).

Table 10
Characteristics of Charleston District
Ocean Disposal Sites

<u>Site</u>	<u>Depth</u> <u>m</u>	<u>Area</u> <u>n mi²</u>	<u>Distance</u> <u>n mi</u>
Georgetown Harbor	9	1.1	3.5
Charleston Harbor	11	11.8	6.7
Port Royal Harbor 1	6	0.8	4.9
Port Royal Harbor 2	13	1.0	7.7

The surficial sediments on the floor of the Atlantic Ocean off South Carolina are almost entirely sandy in relation to grain size and are well sorted with respect to texture (Hollister 1973).

Savannah District

Both ocean dredged material sites within the District are of medium size (average 3 square nautical miles), are in shallow water (11 to 12 m in depth) and are an average of 5.5 nautical miles offshore in the Contiguous Zone (Table 11). Sand-sized material predominates in the submarine surface sediment of the inner continental shelf off the coast of Georgia. Hollister (1973) shows two small, nearshore areas where silt constitutes 20 to 40 percent of the sediment. These areas are just south of Altamaha Sound and St. Andrews Sound, respectively. In addition, a patch containing 10 to 30 percent gravel appears just offshore along the 32nd parallel.

Table 11
Characteristics of the Savannah District
Ocean Disposal Sites

<u>Site</u>	<u>Depth</u> <u>m</u>	<u>Area</u> <u>n mi²</u>	<u>Distance</u> <u>n mi</u>
Savannah River	12	3.9	4.5
Brunswick Harbor	11	2.1	6.6

CARIBBEAN

United States territorial holdings in the Caribbean fall under the jurisdiction of the Jacksonville District and Region II of the USEPA. Five dredged material disposal sites are located off Puerto Rico, and all are in water greater than 200 m deep, have an area of 1.0 square nautical mile, and most lie in the Territorial Sea (Table 12).

Table 12
Characteristics of the Caribbean Disposal Sites

<u>Site</u>	<u>Depth</u> <u>m</u>	<u>Area</u> <u>n mi²</u>	<u>Distance</u> <u>n mi</u>
San Juan Harbor	263	1.0	2.2
Arecibo Harbor	284	1.0	1.8
Mayaguez Harbor	200	1.0	2.8
Ponce Harbor	360	1.0	3.8
Yabucoa Harbor	731	?	4.5

Only two of the five sites were used for disposal of dredged material in the 1979-85 span of years. In that time, San Juan Harbor was dredged twice, yielding 1,624,911 cu yd of maintenance material, and Arecibo was dredged once to produce 199,650 cu yd of material. Both quantities were disposed in their adjacent ocean dredged material disposal sites.

Puerto Rico rises from a relatively shallow, submerged bank of limestone. It has a low-lying shoreland that rises into distinctly calcareous mountainous regions. The foreshore and seabed display calcareous marls, sands, and coral reefs.

Jacksonville District (General)

The Jacksonville District's jurisdiction includes Peninsular Florida from Fernandina in the Atlantic around to the Aucilla River which empties into the Gulf of Mexico some 35 miles east of Tallahassee. Geomorphically the District is situated in two regions, viz., the South Atlantic Bight from Fernandina to Cape Canaveral and the Peninsular Florida geomorphic region from Canaveral to Cape San Blas in the Gulf. Since it also regulates dredging in Puerto Rico and the US Virgin Islands, the District is responsible for maintaining the Federal navigation channels of 14 harbors in Florida and Puerto Rico. The average annual dredging requirement of the entire Jacksonville District is about 12.8 million cu yd.

Because of the District's broad sphere of jurisdiction and because it operates in the Caribbean Sea, the Atlantic Ocean, and the Gulf of Mexico, its ocean disposal sites are discussed under three headings--Caribbean, Atlantic, and Gulf.

Jacksonville District (Atlantic)

The seven Atlantic ports under the District's jurisdiction are Fernandina, Jacksonville, Canaveral, Fort Pierce, Palm Beach, Port Everglades and Miami. In the 7-year span of 1979 through 1985, all but St. Augustine and Miami were dredged one or more times. In fact, Fernandina, Jacksonville, and Palm Beach were dredged six times, and Canaveral five. In the course of this work, the District ocean-disposed 17,114,634 cu yd of material at six Atlantic disposal sites, i.e., all sites listed in Table 13 except Miami Beach. At this writing, the Jacksonville District has the only three disposal sites near or over 100 m in depth on the entire Atlantic seaboard. The remaining sites average only 11.25 m in depth, are of medium size (averaging 1.1 square nautical mile), and are on average just barely outside the Territorial Sea (3.49 nautical miles offshore).

Table 13
Characteristics of Jacksonville District's Atlantic Sites

<u>Site</u>	<u>Depth</u> <u>m</u>	<u>Area</u> <u>n mi²</u>	<u>Distance</u> <u>n mi</u>
Jacksonville Harbor	14	1.0	5.0
Canaveral Harbor	14	2.7	4.8
Fort Pierce Harbor	15	1.0	4.6
Palm Beach Harbor 1	2	0.1	0.2
Palm Beach Harbor 2	156	1.0	3.4
Port Everglades Harbor	98	0.9	2.1
Miami Beach	160	1.0	4.3
Fernandina	12	1.0	6.2

Because only 7 of the District's 26 ocean sites in the continental United States have been used since 1975, the CE has plans to place 10 in the undesignated category. Because of the large number of navigation channels that the District must maintain, it generates more dredged material from maintenance projects than most other Districts on the Atlantic coast. Moreover, even though it is well behind New Orleans and Galveston in total volumes, it leads both of them in terms of the total amount going into ocean disposal sites.

Hollister (1973) depicts surficial sediments on the continental shelf east of Florida to be predominantly sand except for the nearshore area between St. Augustine and Cape Canaveral, which is classed as silty sand. Hard banks and reefs are sparsely scattered along almost the entire east coast of Florida.

GULF COAST

The Gulf of Mexico is served by four Corps Districts (Jacksonville, Mobile, New Orleans, and Galveston) that have jurisdiction over 36 dredged material disposal sites. The Mobile District is the largest in the CE in terms of personnel, and the New Orleans District generally dredges more maintenance material than the other Gulf Districts combined.

Jacksonville District (Gulf)

In 1981 the Jacksonville District had 12 dredged material disposal sites in the Gulf. However, at this writing it has only two, Charlotte Harbor and Tampa 4, and the latter was only designated in 1987 (Table 14). In the years from 1979 to 1985, Charlotte Harbor was dredged three times to yield 1,177,089 cu yd of maintenance material, all of which was ocean disposed. The Port of Tampa is the largest port in Florida, and nationwide it ranks ninth in total tonnage and fourth in export tonnage (phosphate rock). Deepening of 47 miles of main channels and several more in two branch channels generated 73 million cu yd of sediment. In the 7-year span from 1979 through 1985, some 15,931,515 cu yd of material taken from Tampa Bay was disposed of in the ocean. More of the material was used to enlarge existing islands in the harbor and to fill diked areas that will be developed into islands or was distributed along the main channel or on adjacent coastal beaches.

Table 14
Characteristics of Jacksonville
District's Gulf Sites

<u>Site</u>	<u>Depth</u> <u>m</u>	<u>Area</u> <u>sq mi</u> ²	<u>Distance</u> <u>n mi</u>
Charlotte Harbor	12	1.0	7.2
Tampa 4		4.0	18.0

The west Florida shelf is wide and exhibits prominent carbonate rocks and extensive coral reefs in the southern part. Unconsolidated sediments include recent and relict carbonate sediments that are thin and discontinuous. The vast majority of this sediment veneer is biogenous (coral debris, mollusc shells, foraminifera tests) in origin. Scattered low outcrops of limestone and chert provide a substratum for coral, sponge, and other epifaunal growth.

Mobile District

The Mobile District has jurisdiction over nine ocean dredged material disposal sites in the northeastern Gulf of Mexico. Two of them are worthy of special note, viz., Mobile North and Mobile South, which both have areas of 50 square nautical miles. Both of these large areas are new. Mobile North encompasses the old area and some new areas. Four of the sites are in Florida, two are in Alabama, and three in Mississippi (Table 15).

Sediments between the Mississippi Delta and western Florida have been described by Upshaw, Creath, and Brooks (1966). Their work reveals that Mississippi Sound sediments are composed mostly of silt and clay with some areas of fine to medium sand. Medium and coarse sands dominate the mainland beaches west of Pascagoula River and along the lee side of the barrier islands. Those areas seaward of the islands are mostly fine sands except for a notable, elongate mud area just off Dauphine Island. Fine sands, silts, and clays border the mainland east of Pascagoula and dominate the sediments of Mobile Bay. In general, one can conclude that particle size diminishes from the predominantly sandy bottom off Florida (Rinkel and Jones 1973) westward to the fine silts and clays of Mississippi. Except for local interruption, coarse and medium sands on the open shelf east of Mobile Bay grade into fine and very fine sands which in turn give way to silt and clay muds; the same trend also continues from north to south across the continental shelf. Sediments with a high percentage of sand encompass the Chandeleur Islands with fine sediments occupying the interior of the arc formed by the Chandeleurs (Coleman and Gagliano 1964).

Table 15
Characteristics of the Mobile District
Ocean Disposal Sites

<u>Site</u>	<u>Depth</u> <u>m</u>	<u>Area</u> <u>n mi²</u>	<u>Distance</u> <u>n mi</u>
Port St. Joe 1	12	1.57	2.75
Port St. Joe 2	13	1.19	4.75
Panama City	16	0.26	1.0
Pensacola (nearshore)	11	0.7	2.6
Pensacola (offshore)	24	1.8	9.7
Mobile--North	14	50.0	5.2
--South	16	50.0	7.0
Gulfport 1	8	5.22	0.6
Gulfport 2	8	2.47	1.5

New Orleans District

The New Orleans District dredges more sediment each year than any other two Districts combined, including Galveston and Mobile. At the present writing, the District has reduced its previous 19 ocean dredged material disposal sites to 15 by combining the previous seven Calcasieu River and Pass sites into three. Thus, Site 1 was previously Sites B and F; Site 2 was previously Sites A, C, and G; and Site 3 was previously Sites D and E. Hence, the District has not lost any area into which to dispose of material. Moreover, they no longer dredge South Pass so that the future of the Mississippi River South Pass site is uncertain, but there is no extant plan to withdraw it from the register. As can be seen in Table 16, the typical New Orleans ocean site is shallow, of moderate size, and located in the Territorial Sea. Some sites that appear to have considerable haul distances in truth do not, because like Calcasieu Pass Site 3, they are located alongside the channel that requires maintenance dredging.

Surface sediments on the inner continental shelf of Louisiana from the Mississippi River to Sabine Pass and out to a depth of about 30 m are highly variable in both physical and chemical characteristics (Tieh et al. 1973). Sedimentary facies in the silt-clay mode that contain varying amounts of sand tend to predominate the nearshore area except for a stretch extending from Bastian Bay to a point just west of Isle Dernieres. In that area the sediments are by modes in the fine to very fine sand classes; similar surficial sediments are found offshore of Atchafalaya and Vermilion Bays. Coarser sands in the form of relict sediments are reported offshore in the western part of the area in the vicinity of Calcasieu Pass.

Table 16
Characterization of New Orleans District
Ocean Disposal Sites

Site	Depth m	Area n mi ²	Distance n mi
Mississippi River Gulf Outlet	6	4.0	9.0
Mississippi River South Pass	17	0.4	1.7
Mississippi River Southwest Pass	6	3.2	2.7
Mississippi River Tiger Pass	2	1.1	1.2
Empire-Bayou Fontanelle Waterway	3	0.1	0.4
Baratana Bay Waterway	3	0.9	1.9
Bayou Lafourche Waterway	3	0.3	0.8
Houma Navigation Channel	4	2.2	10.0
Atchafalaya River	4	6.5	7.0
Mermentau River A	4	0.2	0.9
Mermentau River B	5	0.3	1.2
Freshwater Bayou	4	0.7	1.9
Calcasieu River and Pass			
Site 1	4-5	2.3	1.5
Site 2	2-6	4.7	1.6
Site 3	11.5	7.0	12.8

In 1985 the New Orleans District estimated that it annually dredges 70 million cu yd, of which 20 percent is disposed on land, 60 percent into estuaries, and 20 percent into the ocean. In the year 1987, the District dredged 96,081,261 cu yd, of which 14,236,820 cu yd or 14.8 percent was disposed into the ocean.

Galveston District

The Galveston District ranks second behind New Orleans among all the Corps Districts in the amount of dredged material to be dumped. Although its 367 miles of coastline places Texas only third in the Gulf of Mexico behind Florida with 770 miles and Louisiana with 397, the Texas coast provides harbors for about 30 ports between Port Arthur on the Texas-Louisiana border and the Port of Brownsville near the United States International border with Mexico. Some of the port channels are very long and generate large quantities of maintenance material when dredged. Also, the Galveston District is responsible for maintaining several hundred miles of Gulf Intracoastal Waterway that course from Orange, TX, in the east to the western terminus near Port Isabel.

The Galveston District has 10 offshore dredged material disposal sites. In addition to these, the District has upland sites, as well as diked intertidal sites along the bay shores and the Gulf Intracoastal Waterway. According to recent figures (1987), about 40 percent of the maintenance material is placed in containment sites, 45 percent into diked intertidal and open water sites (for example, Galveston Bay), and 15 percent goes offshore (Table 17).

Table 17
Characteristics of Galveston District Ocean Disposal Sites

<u>Site</u>	<u>Depth</u> <u>m</u>	<u>Area</u> <u>n mi²</u>	<u>Distance</u> <u>n mi</u>
Sabine-Neches Waterway			
1	11	2.4	15.0
2	11	4.8	12.8
3	12	4.7	8.0
4	7	4.2	4.2
Galveston Harbor	12	6.4	5.4
Freeport Harbor	9	0.4	1.7
Matagorda Channel	8	0.4	2.1
Corpus Christi Channel	11	0.4	2.2
Port Mansfield 1	8	0.1	0.9
Brazos Island Harbor	14	0.6	1.7

The Galveston District has less difficulty with contaminated dredged material today than it did 8 to 10 years ago. In part this is the result of having placed contaminated maintenance material in containment sites from which leachable metals could not escape and be redistributed into the bays. As in other Corps Districts, Galveston has been losing the use of historic sites simply because island sites have become bird sanctuaries and some diked intertidal sites have become marshes or other valuable water-edge habitat.

The typical offshore dredged material disposal site has an area of 2.5 square nautical miles and is situated 5.5 nautical miles offshore where the water averages 10.3 m in depth. The Texas shelf is wide and covered with silty clays that alternate with bands of sand that frequently begin near shore. The two Sabine-Neches sites that are far offshore are actually along the waterway where the material to go in them is dredged.

The Galveston District as of 1986 estimated that it would have to continue to dredge 40 million cu yd of sediment each year to maintain navigation channels. However, proposed projects to deepen channels in Galveston Bay, Houston Ship Channel, Corpus Christi Inner Harbor, Freeport Harbor, and the Port of Brownsville will generate about 200 million cu yd of new work material.

PACIFIC COAST

The discussion in this section of the guide is limited to the five Corps Districts on the Pacific seaboard, including Alaska. The sites in the territorial holdings of the United States will be discussed in the Pacific Ocean section that can be found at the end of this part. At the present time, 26 ocean dredged material disposal sites exist among the five Districts.

The Pacific Coast of the United States is subdivided into four geomorphic regions, as follows:

- a. Southern California Bight, extending from Punta Eugenia to Point Conception (see Figure 10). The Los Angeles District occurs here.

- b. Northern California Shelf, which includes the coast from Point Conception to Cape Mendocino. The San Francisco District covers this area.
- c. Northwest Shelf, extending from Cape Mendocino to Vancouver Island. The Portland and Seattle Districts divide this coastal area, with the Columbia River marking the division point.
- d. Gulf of Alaska, which is limited to that part of Alaska bordering on the Pacific Ocean.

The geophysical characteristics of these four regions are discussed separately under the related Corps Districts. It is noteworthy that the California disposal sites, especially the southern ones, are much deeper than those off the coast of Oregon, Washington, and Alaska. Primarily this is related to geomorphic characteristics, particularly the width of the mainland shelf and the steepness of the adjacent slope.

Los Angeles District

The Los Angeles District is responsible for five ocean dredged material disposal sites (Table 18); however, it disposes of the smallest amount of dredged material of any District on the Pacific Coast except Alaska.

The Southern California Bight is characterized by mountainous shorelands, narrow mainland shelves, steep slopes with canyons, basins and offshore islands, and a paucity of marshes, swamps and calcareous bottoms.

Table 18
Characteristics of Los Angeles District Disposal Sites

Site	Depth m	Area n mi ²	Distance n mi
San Diego-Point Loma*	86	0.8	8.2
San Diego-100 fathoms	168	0.8	7.4
Newport Beach	457	0.8	4.3
Los Angeles	195	0.8	5.2
Port Hueneme	366	0.8	3.9

* The District hopes to dedesignate this site.

The five sites range in depth from 86 to 457 m with an average of about 254 m. All of them have an area of 0.8 square nautical mile and are located an average of 5.8 nautical miles offshore (range 3.9 to 8.2 nautical miles).

Typically, the sediment cover in the Southern California Bight is patchy and thin on banks and shelves but is relatively thick in deep basins (Gorsline 1975). This area has an almost unique continental shelf in that there is a narrow mainland shelf that plunges down a steep slope into deep basins, the outer wall of which rises to an offshore island. The shelf continues seaward of the islands before terminating in the true continental slope. Existing surficial sediments on the continental shelf tend to be shallow detrital sands containing various amounts of organic and authigenic sand-sized material (Moore and Shumway 1959). Submarine canyons and their associated fans are the major sources of sediment

input for the deeper basins; those basins near the coast (e.g., the basin between Los Angeles and Catalina Island) have thicker fill and more developed canyon-fan systems (e.g., Scripps and La Jolla Canyons just north of San Diego) than do distant outer basins. At the present time, the sand supply brought to the coastal waters and transported southward to beaches and canyons has been reduced drastically because of construction of water-conservation dams in the main canyons of nearby mountains.

San Francisco District

The San Francisco District has four ocean dredged material disposal sites under its jurisdiction (Table 19); however, studies are under way to designate a new ocean site at Humboldt Bay Harbor and to designate additional sites for fine-grain sediments off San Francisco. Increasing opposition to continued in-bay disposal of dredged material may significantly increase the volume of sediments scheduled for ocean disposal. Currently, the District uses ocean sites for disposal of the second largest volume of dredged material among the Pacific coast districts.

Table 19
Characteristics of San Francisco District
Disposal Sites

Site	Depth m	Area n mi ²	Distance n mi
San Francisco Channel	11	1.2	6.8
Noyo River	24	0.05	1.4
Humboldt Bay Harbor	21	0.02	1.3
Crescent City-100 fathoms	183	0.2	10.0

The northern California Shelf is characterized by a predominantly mountainous shoreland. Although the shelf is wider than the mainland shelf of southern California, it is narrow compared to the Gulf of Mexico and parts of the Atlantic Coast. It has a very steep continental shelf, but unlike the Southern California Bight, it has large stretches without canyons or offshore insular developments.

Surficial sediments on the continental shelf off the entrance to San Francisco Bay are predominantly shell sands and glauconitic sands, whereas sediments on the adjacent slope range from fine sands through coarse silts to fine silts (Bailey 1966). Along the central coast, shelf sediments are generally shallow, and in many locations off California the surface sediments are bound into nodules that consist of fine sand, shell fragments, and animal tubes bound together with a phosphate cement.

Portland District

The Portland District has the largest maintenance dredging requirement of all the Districts along the western seaboard. Seventeen ocean dredged material disposal sites are within its jurisdiction (Table 20). All but two sites are situated in the Territorial Sea, all are small in size, averaging about 0.14 square nautical mile, and are generally shallow, averaging about 25 m in depth. The Depoe Bay site has never been used, the Port Orford

site has only been used once, and both the Siuslaw River and Tillamook Bay sites will probably be moved.

The Portland District is in the Northwest Shelf geomorphic region, which encompasses the area from Cape Mendocino to Vancouver Island. The geomorphology here is characterized by a typically rocky coast, which has few bays but is incised by canyons and submarine canyons. Surface sediments on the nearshore shelf in the Portland District are primarily sands composed of detrital quartz and feldspar. This sand zone extends from the shoreline out to a water depth of about 90 m off the central and northern Oregon Coast. Off the coast of southern Oregon, however, the sands form a narrow belt in shallow water and then give way to a zone of mixed sand and mud and areas of exposed bare rock (Kulm and Fowler 1970).

Table 20
Characteristics of Portland District Disposal Sites

Site	Depth m	Area n mi ²	Distance n mi
Chetco River Entrance	21	0.09	0.9
Rogue River Entrance	21	0.14	1.2
Port Orford	15	0.03	0.2
Coquille River Entrance	20	0.14	0.9
Coquille River Entrance (10)	21	0.21	0.5
Coos Bay E	17	0.14	1.3
Coos Bay F	24	0.14	1.3
Coos Bay H	50	0.14	3.7
Umpqua River Entrance	32	0.10	0.8
Siuslaw River Entrance	21	0.07	1.0
Yaquina Bay	18	0.25	1.2
Yaquina Bay (103 Site)	25	0.24	0.5
Depoe Bay	27	0.03	0.9
Tillamook Bay Entrance	29	0.14	1.3
Columbia River A	18	0.27	2.7
Columbia River B	40	0.27	4.0
Columbia River E	21	0.11	0.0
Columbia River F	38	0.09	4.3

Seattle District

The Seattle District has three ocean dredged material disposal sites under its jurisdiction (Table 21). As with the Portland District, Seattle is located in the Northwest Shelf geomorphic region, which is characterized by rocky coasts with few bays. Puget Sound is a fjord-type estuary. Most of the offshore sediments are sand, but one of the proposed sites (8-Mile Site) has a large lens of gravel surrounded by sand.

Table 21
Characteristics of Seattle District Disposal Sites

<u>Site</u>	<u>Depth</u> <u>m</u>	<u>Area</u> <u>n mi²</u>	<u>Distance</u> <u>n mi</u>
Willapa Bay	11	3.5	3.5
Grays Harbor			
8-Mile Site	45	0.39	8.0
Southwest Site	40	1.59	4.3

Alaska District

This Corps District has jurisdiction over two ocean dredged material disposal sites in the vicinity of Nome, Alaska (Table 22). Both sites are small and located near shore in shallow water. Nome is located on the north coast of the mouth of Norton Sound. The surficial sediments of the Bering Sea are sand inshore and then grade to silts near the shelf break. The deep basins are covered by clayey diatomaceous oozes.

Table 22
Characteristics of Alaska District Disposal Sites

<u>Site</u>	<u>Depth</u> <u>m</u>	<u>Area</u> <u>n mi²</u>	<u>Distance</u> <u>n mi</u>
Nome, East Site	5	0.40	0.4
Nome, West Site	5	0.34	0.4

PACIFIC OCEAN

United States territorial holdings in the Pacific Ocean come under the jurisdiction of the Honolulu, Hawaii, Corps District. Eight ocean sites fall in this category, as shown in Table 23. Because all the sites are adjacent to volcanic islands, they are situated in very deep water.

Table 23
Characteristics of the Pacific Ocean Sites

<u>Site</u>	<u>Depth</u> <u>m</u>	<u>Area</u> <u>n mi²</u>	<u>Distance</u> <u>n mi</u>
Kauai/Nawiliwili	1,120	0.8	3.3
Kauai/Port Allen	1,610	0.8	3.2
South Oahu	475	1.5	3.3
Maui/Kahuli	365	0.8	5.0
Maui/Hilo	340	0.8	4.0
Apra Harbor, Guam	1,995	0.8	3.7

Surface sediments on the insular shelves are primarily calcareous sand and coral rubble, with a small amount of silt or mud. The sediments on the shallow slopes and terraces are commonly littoral sands (pure or mixtures of detrital and biogenic calcareous grains) that have been transported downslope by mass movement. Ocean floor sediments at water depths of 2,000 m or more contain very little terrigenous input. Rather they are either of pelagic biogenic origin in the form of siliceous oozes or are brown clays typical of deeper aspects of the Pacific Ocean. Also, throughout these deep surficial sediments one finds darker basaltic fragments of past volcanic activity.

PART V: SELECTING AN OCEAN DISPOSAL SITE FOR DREDGED MATERIAL

INTRODUCTION

The 1970s saw the growth of serious movements to ban the disposal of all wastes into the ocean, but in the mid-1980s a reversal of that trend became evident and the sentiment is growing among **knowledgeable** people that the ocean can be the most appropriate of receiving environments for salt-laden dredged material. Since the beginning of the serious environmental movement in the United States and elsewhere, all wastes including municipal sewage effluents, industrial residues, and dredged material were lumped together and treated as one and the same by regulators. Gradually, however, facts on the geochemical nature of dredged material, generated in large measure by the Dredged Material Research Program of the US Army Engineer Waterways Experiment Station, convinced responsible people that dredged material possessed components that could bind pollutants in such a way that when on the ocean floor they were not available to the biota. These findings, together with the fact that land disposal could under some conditions actually free the pollutants, caused the contracting parties of the London Dumping Convention to recognize that dredged material should not be classed with industrial and municipal wastes. Accordingly, they accepted advice from their scientific advisors and created realistic guidelines for the ocean disposal of dredged materials in 1987. The task before us here is to provide a technique for site selection, which is based upon the orderly application of data to arrive at the best possible specific location for a dredged material disposal site in the ocean area under consideration. Since most such sites will be located either on the continental shelf or the continental slope, let us examine briefly the relevant characteristics of these environments. For those sites deeper than 200 m, the reader is referred to Pequegnat et al. (1978).

The Continental Shelf

The most used and mis- used part of the ocean

Even though the continental shelf underlies a scant 7.5 percent of the total area of the oceans and is flushed by only a small portion of their volume, much of man's utilization of the sea is confined to it. For the most part this is true of the disposal of wastes. Thus, with few exceptions, such as off Hawaii, Puerto Rico, Guam, and American Samoa, ocean dredged material disposal sites are located on the shelf's inner part. It is here also that a great harvest of finfish and shellfish is taken; it is here that quantities of petroleum and gas are extracted; it is here that sands, gravels, and some precious stones are mined; it is here that sports fishing, sailing, and other recreational pursuits occur off major and minor harbors; and, in the midst of it all, it is here that many wastes in addition to dredged material are effectively disposed of in substantial amounts.

The question inevitably arises in the minds of managers of the ocean environment and environmentalists alike, How much waste can the waters and sediments of the shelf assimilate before damaging processes result? There may be no simple answer to the question, although it seems likely that it can take much more dredged material. It is evident that the crucial aspect of the problem is not really so much whether or not man should

stop disposing of wastes on the shelf, but rather how disposal should be done with regard to the oceanographic characteristics of the shelf in general and the specific characteristics at a given site. In other words, this important area must be managed with understanding by representatives of all the users of the shelf. It is for this reason that each manager of dredged material disposal must have a working knowledge of the continental shelf in the area of concern.

Oceanography of the shelf

The continental shelf is the submerged margin of a continent, and, by extension, it is also considered to include the shallow margins of oceanic islands. United States laws define the continental shelf as the seaward extension of the coast to a depth of 600 ft. It slopes seaward gradually from shore with an average drop of about 12 ft per mile. Its outer limit, the shelf break, is marked by an increase in gradient to about 80 m per nautical mile. This is the beginning of the continental slope that moves down to the deep-sea bottom. The shelf break generally occurs at some depth between 110 and 146 m.

The continental shelf varies considerably in width, ranging from a few miles off the west coast to as much as 135 or so nautical miles off parts of the Gulf coast. One might think that these relatively narrow and shallow areas, over which only 0.1 percent of the ocean's waters lie, would be poor receptacles for wastes. But this is not the case, at least at the present time. The reason is simply that the shelf is a high-energy environment that is markedly affected by wave, swell, and strong currents of onshore, offshore, or longshore types. It is much more variable than the oceanic region on its seaward border.

Even though all of the marine environments are in potential continuity, the sea is certainly not homogeneous. Nearshore waters are influenced by the continental climate; they are modified by the proximity of estuaries and coastal lagoons; they are freshened and nourished by runoff from streams; and their bottoms are not far removed from the sea surface. Proceeding away from shore the continental climate gives way to the maritime climate; the influence of estuaries, lagoons, and streams becomes less pronounced; and the depths become progressively greater until the abyssal plain is reached. These basic factors are reflected in the nature of the water columns and the bottom environments, which are subdivided into zones each of which is characterized by its own suite of temperature, salinity, turbidity, nutrient, current pattern, and sediment conditions. Some of the changes occur gradually while others are more abrupt. As the environments change with depth and distance from shore, so do the living systems that inhabit the environments. Such changes in environments and the biological systems they support must be taken into account in any consideration of the effects of the disposal of dredged material in the marine environment, because the effects will vary depending upon which systems receive the materials (Pequegnat et al. 1978).

Shelf ecosystem

The nonliving components of these systems, which together with their living entities are called ecosystems, include the atmosphere above the water, the water column itself, and the floor of the sea.

Atmosphere. The atmosphere above the water is of primary importance to the present discussion because water mass movement is induced largely by the frictional force of winds passing over the water surface. Wind-driven currents play a major role in the

horizontal spread of organisms and of many materials discharged at sea. Turbulence, involving vertical water movement, creates a mixing layer where wastes are diluted and into which nutrients are brought from deeper waters into the lighted zone, especially in fall and winter, where photosynthesis takes place in late winter and spring. The wind also creates waves that will move sediments far more effectively than currents. Major atmospheric events (storms) may often cause dramatic changes over a short time period.

The temperature of the air also determines the temperature of the near-surface water, especially in coastal areas where the water is shallower. Sunlight, transmitted through the atmosphere, penetrates the water surface and supplies the radiant energy required for growth of minute marine plants called phytoplankton. Exchange of gases between the sea and the atmosphere also takes place at the air-sea interface. Thus it is that the atmosphere is of paramount importance in regulating environmental conditions in the surface waters of the sea, and by so doing it is largely responsible for regional differentiation of coastal waters.

Light. The seasonal progression of the sun determines that greater amounts of heat and light will be received by the surface waters during late spring, summer, and early fall than during the winter, when the sun is more directly over the southern hemisphere. Much of the sunlight striking the sea surface is reflected back into the atmosphere, and that which does penetrate the sea surface is rapidly scattered and absorbed by water molecules and by smaller suspended particles. For these reasons, sunlight is attenuated in seawater by a logarithmic function of depth. Even in very clear ocean water about 55 percent of the incident radiation at the surface has been absorbed after penetrating to a depth of about 1 m and only 1 percent is left at some depth between 50 and 100 m. In very turbid coastal waters, 83 percent is gone in the first meter and only 1 percent remains at the 5-m depth. Phytoplankton growth, which is the basal component of the ecosystem, is limited by the quantity of light available for photosynthesis, and phytoplankton generally cannot carry on photosynthesis when the light level is less than 1 percent of the surface value. Therefore, the depth of the euphotic zone, which is the upper layer of the sea where light is sufficient to support photosynthesis, tends to be greater in the open sea than in more turbid coastal waters, greater in summer than in winter, and greater in tropical latitudes than in temperate or polar latitudes.

Temperature and density. When the short-wave energy of the sun penetrates into the water, it is absorbed and causes the temperature of the sea to rise. As a result the surface waters may become sufficiently less dense than the deeper layers so that a condition of thermal stratification is established. Thus, a shallow surface zone of nearly uniform density and nearly uniform high temperature is formed. It is then characteristic that below this surface zone there is a zone where temperature decreases and density increases rapidly with depth, making the thermocline and the pycnocline or, if they occur together, the thermopycnocline. The rate of change of density with depth determines the water column's stability or unwillingness to move vertically. On occasion turbulence may be unable to penetrate through this stable layer. Thus, exchange of materials between the layers above and below the thermopycnocline is markedly reduced. Materials that have densities just slightly greater than that of seawater tend to accumulate on the pycnocline or thermocline. The waters over many of the US dredged material disposal sites will be too shallow to have either a pycnocline or thermocline unless, of course, they are downcurrent of rivers where fresh water will override the seawater. Those of intermediate

depth, however, will display a shallow seasonal thermocline during the warm months. It will disappear in the fall when the winds increase and overturn the water column. Those disposal sites over 200-m depth will very likely have a deep permanent thermocline, a summer thermocline, and a pycnocline.

Dissolved oxygen. The atmosphere is the main source of oxygen dissolved in seawater, and at the surface the water is usually very close to being saturated. In fact, at times (especially in spring), the water is supersaturated with oxygen that is a by-product of the photosynthesis carried on by the phytoplankton. Below the surface layers the water is seldom saturated because oxygen is consumed by living organisms and oxidation of organic detritus faster than it is transported from the air-sea interface. At depths between 500 and 1,000 m a layer of water occurs in which the oxygen content is less than it is either above or below. This, the oxygen minimum layer, is found only in the water column of the very deep dredged material disposal sites.

Zonation of the continental shelf

On the basis of their hydrography and biology, three shelf zones are generally recognized: the inner, middle, and outer continental shelf zones. The inner zone extends from shore out to a depth of 20 m or so. As noted earlier, something over 70 percent of the ocean dredged material disposal sites are located in this inner zone. This zone is generally very productive of marine plants from minute plankters to giant kelps. Most of the migratory finfish and invertebrates that spend parts of their lives in estuaries, such as croakers, spot, sand seatrout, and the white and pink shrimps, spend the remainder of their lives in the inner shelf zone. Local variations in salinity (and therefore density) play important roles in controlling the direction of currents on the shelf (Emery 1969). Thus, the lower salinity adjacent to the mouth of a river results in a higher sea level there than farther out on the shelf; hence, the low-density water flows seaward but as a result of the Coriolis effect turns to the right (when one is facing seaward in the northern hemisphere). Of importance to the fate of disposed dredged material in such places is the fact that as the surface water moves seaward because of density differentials, water must move shoreward along the bottom to replace it. This movement is generally sufficiently strong to transport some sediments landward.

The middle continental shelf zone, being farther from shore and deeper than the inner zone, is less influenced by river and estuarine waters. Also, far fewer estuarine-related species occur here. This zone extends to depths of 70 to 80 m and thus supports most of the dredged material disposal sites of intermediate depth. It is in this middle shelf zone that the density current mentioned above flows the strongest. In many places this flow may be just the opposite of the wave-induced longshore current. This zone is a migration area for some fishes that move into deeper shelf waters in winter (where temperatures may well be higher than inshore) and then return to the inner shelf area or even estuaries in summer.

The outer continental shelf zone is only slightly affected by coastal phenomena. Salinities are higher, approximately those of the open ocean, and bottom temperatures are nearly uniform the year round. Hence, in winter they may be higher than those of shallow inshore waters that radiate heat to the colder atmosphere as fronts move across them. This outer shelf zone, which runs from the 80-m depth out to near the shelf break, is typically a relatively flat plain with some low-relief features that vary regionally. For instance, off

New England, ridges and valleys characteristic of glacial moraine topography are observed; drowned reefs are seen off the southern and western coasts of Florida; diapiric hills (often salt domes) punctuate the otherwise flat shelf of the northern Gulf; off the West Coast, thrust fault blocks are not uncommon; and finally, off the Hawaiian and Caribbean islands drowned coral reefs and some submarine volcanic features are observed. It is important to note also that the outer continental shelves of nearly all coasts are incised by the upper reaches of submarine canyons that continue down the continental slope. Off the West Coast of the United States the mainland shelf is so narrow that the heads of many canyons are close to shore where they trap and transport into deep water the sands that are being moved along southward in the inner shelf zone by wind-driven waves and their associated currents. Elsewhere the currents of the outer shelf are very much influenced by those of the open ocean over the slope. Many animals reside in the outer zone, including in the Gulf of Mexico such shellfish as the brown shrimp.

One may document the multiresource nature of the continental shelves by noting that about 90 percent of the world's marine food resources, now caught and processed at the rate of several billions of dollars per year, comes from the shelves and adjacent bays. At the same time about a fifth of the total world production of oil and gas, amounting to something over \$4 billion per year, comes from the shelf. Interestingly, the third shelf resource in terms of present dollar value (\$200 million per year) is sand and gravel.

The Continental Slope

Oceanography of the continental slope

Even though only a few of the ocean dredged material disposal sites are situated on the continental slope, it is useful to compare its oceanographic characteristics with those of the shelf. The slope may be thought of as a transition area between the shallow, highly productive waters of the shelf, and the less productive waters of the deep oceans. However, as shall be noted later, the slope has its own unique fauna.

The continental slope is the most significant topographic discontinuity of the earth's crust because it marks the general position of the contact between low-density rocks of the continents and the high-density rocks of the ocean floor (Emery and Uchupi 1972). The area of the slope is about twice that of the continental shelf, occupying 15.3 percent of the total area of the oceans, as compared with the 7.6 percent of the shelf. The slope has grades over 3 deg and sometimes as high as 25 deg. Most profiles across the continental slope show a steep, irregular upper slope and a smooth lower slope. Such are the cases for the northwestern Gulf of Mexico continental slope with its upper "hummocky zone" of diapiric structure origin and those of the Atlantic seaboard that possibly reflect a change from an erosional slope to a slumped and debris-covered slope. Directly off southern California and within the continental borderland the slope is a dip slope, whereas off Oregon and Washington, the slope is broken by normal faulting parallel to the shoreline.

In general, the sediments of the continental slope are of a smaller grain size than those collected from the shelf but contain a higher percentage of organic matter than those on the shelf or on the deep-sea floor. Mass movements of these sediments may be common because the steepness of the slope is probably near the angle of repose of the sediment.

The slope zone is not only physically a transition between shelf and abyss, but also dynamically a transition zone. The upper slope receives some organic matter from the

shelf and shares some species with the shelf; the middepth slope, with its own faunal assemblages, receives its organic matter from mesopelagic sources; and the lower slope, below 1,000 m, is influenced by deeper currents and has yet another faunal assemblage. The fauna of the slope is characterized by its similarity in all the world ocean. It is to be expected that the slope is less productive than the shelf, but it is by no means certain what the values are. So far as invertebrates are concerned, it is estimated that the biomass of the slope regions is only 10 percent of the shelf. However, it must be pointed out that most of the bottom-feeding fish, which are commercially important in shelf fisheries, also feed in the upper slope zones down to 700 to 800 m.

Zonation of the upper continental slope

The continental slope appears to support distinctive assemblages of bottom-dwelling organisms, some of which are of recognized commercial value or have that potential at and above depths of 1,000 m. In the Gulf of Mexico, Pequegnat et al. (1983) recognized the Shelf-Slope Transition Assemblage and three True Slope Assemblages between the shelf break and depths of 1,050 m. Similar but not identical assemblages are found on the continental slopes of both the Atlantic and Pacific coasts.

According to the National Marine Fisheries Service in Pascagoula, MS, the only commercial fisheries on the outer shelf and upper slope of the Gulf of Mexico are the red snapper and royal red shrimp. The most abundant demersal fish species here is the tilefish, but it is not fished commercially in appreciable amounts. Pelagic sport fish, such as marlin, occur over the shelf-slope intersection during the warm periods of the year.

The fishing industry of the northeastern United States is large and varied. Some 19 species of finfish and shellfish are fished on the upper continental slope. Principal among these are the lobster, cod, haddock, hake, flounder, ocean perch, scup, and pollock.

In the Middle Atlantic Bight the catch is dominated by a list similar to the above with lesser importance of the cod and haddock. In the South Atlantic Bight there is a pronounced paucity of demersal fishes which range to depths of the outer continental shelf and upper continental slope. It is true that both the royal red shrimp and red snapper live here, but the former is not yet fished in significant numbers.

On the Pacific coast bottom fish caught by trawling represent an insignificant fraction of the total catch, which is dominated by pelagic fish such as tuna or inshore predatory fish such as halibut and rockfish. By contrast, in northern California and the northwest United States, trawling and bottom longlining constitute a large portion of the fish landings. To the south the principal forms are sole, bocaccio, chilipepper, Pacific hake, and pandalid shrimp; to the north are black cod, ocean perch, pollock, Pacific hake, halibut, flounder, sole, pink shrimp, and Tanner crab.

LEGAL AND OTHER CONCERNS REGARDING SITE SIZE

Regulations

In the 11 January 1977 revision of USEPA's ocean dumping regulations and criteria we find the following general criterion dealing with disposal site size:

40 CFR 228.5(d). The sizes of ocean disposal sites will be limited in order to localize for identification and control any immediate adverse impacts

and permit the implementation of effective monitoring and surveillance programs to prevent adverse long-range impacts. The **size, configuration, and location** of any disposal site will be determined as a part of the disposal site evaluation or designation study (emphasis added).

Then in 40 CFR 228.6 (a) (4) we find a specific criterion that relates to size, with regard to proposed use of the site. This states that in selecting a site, consideration will be given to

types and **quantities** of wastes proposed to be disposed of, and proposed methods of release, including methods of packing the waste, if any (emphasis added).

In selecting the size and configuration of a dredged material disposal site, it is our contention that one must be concerned with

- a. Longshore and tidal current speeds and directions.
- b. The proposed average annual amount and types of dredged material to be disposed in the site.
- c. Any plans for expansion or deepening of a harbor that would produce extraordinary amounts of dredged material.

Size, Shape, and Orientation

Following determination of the Zone of Siting Feasibility (Mathis and Payne 1984), attention is directed to site size. This is a local determination that is contingent upon the amount of material to be disposed and other factors, which are discussed below.

The preferred location and orientation of the site should be downcurrent of the mouth of the estuary. In the northern hemisphere the Coriolis effect will cause the low-salinity current leaving the estuary (harbor) to turn to the right and move down the coast along with but seaward of the longshore current. At the same time the tidal bottom water (forming a wedge) will move in from the left; hence, if the site is located as suggested with reference to the harbor entrance, there will be less likelihood that disposed materials will be transported back into the estuary, as wave forces can do.

OCEANOGRAPHIC CONSIDERATIONS

Waves and the Depth Factor

Initial bottom disturbance

Certain characteristics of waves must be defined in order to make this section understandable:

- a. **Wave height** (h) is the vertical distance from the wave trough to crest. Mean wave heights on US Coasts are ordinarily not over 0.7 to 1.5 m.
- b. **Wave period** (p) is the time required for two successive crests to pass a fixed point. Mean wave periods on US Coasts range between 2 and 5 sec with maxima ranging up to 9 sec or so.
- c. **Wave length** (l) is the horizontal distance from crest to crest.

d. **Wave velocity (v)** is the wave length divided by the wave period.

When waves move into shoaling water their periods remain unchanged but their velocity decreases. Because the period is constant while the velocity ($1/p$) decreases, it is evident that the wave length decreases in shoaling water. Waves begin to feel or disturb the bottom when the ratio between water depth and wave length (d/l) is less than 0.5, that is to say when depth has decreased to one half the length of oncoming waves. For waves of periods of 5 sec, this depth is about 20 m.

Threshold of sediment movement

As the velocity of fluid flow over the seabed increases, a point is reached where the fluid exerts enough shear on the grains to cause them to rise from the bed and move horizontally. This point is known as the threshold of sediment movement (Komar 1976). The shear stress exerted on the bottom by wave-induced motion stirs up the sediment, which may then be moved by a current that by itself would have been incapable of reaching the threshold stress.

Transport of Silts and Clays

The dredged material derived from maintenance dredging contains varying quantities of silts and clays; hence, we must consider the conditions under which a disposal mound would be subject to transport by waves or currents or a combination of both. Beds of fine-grained sediments having diameters of $100\ \mu$ or less exhibit a high degree of cohesiveness (Figure 11). Thus, flume studies have shown that the threshold shear stress for compact fine silt or clay beds can exceed that necessary to move gravel-sized material having particle diameters of 2.0 mm or more (Drake 1976). This cohesiveness is produced by

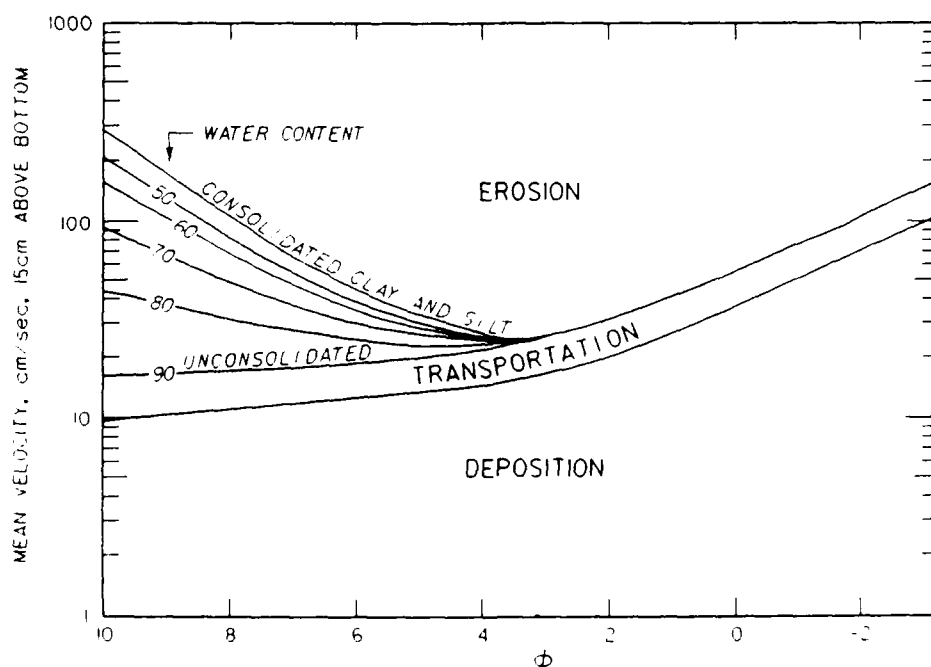


Figure 11. Current velocities required to transport particulate materials (after Postma 1967)

unsatisfied particle charges, the strength of which is dependent in part upon water content of the bed, mineral composition, and content of organic matter. There is, of course, an inverse relationship between compaction and water content, with a water content of 80 percent being of considerable importance (Figure 11). Drake (1976) has concluded that moderately compact mud beds may be eroded at current velocities on the order of 10 to 30 cm/sec, provided the water content is no less than 80 percent. That, however, refers to current speeds 1 m above the bottom; considerably lower velocities are required at the water-sediment interface.

Shoaling transformation of wave structure

An orbital motion of individual water particles occurs in all surface waves. In deep water ($d/l > 0.5$) these particle orbits are nearly circular with their diameters equaling the wave height at the surface but decreasing exponentially toward the bottom. At intermediate bottom depths, the orbits become elliptical and smaller. When the onrushing waves feel bottom, the elliptical motion decays to a back-and-forth motion of the water with the period of motion equaling that of the surface wave. When this oscillatory movement begins it exerts a shear stress on the bottom and the sediment grains start to feel the waves (Figure 12). This stress is several times larger than the shear exerted by a steady current of equal magnitude.

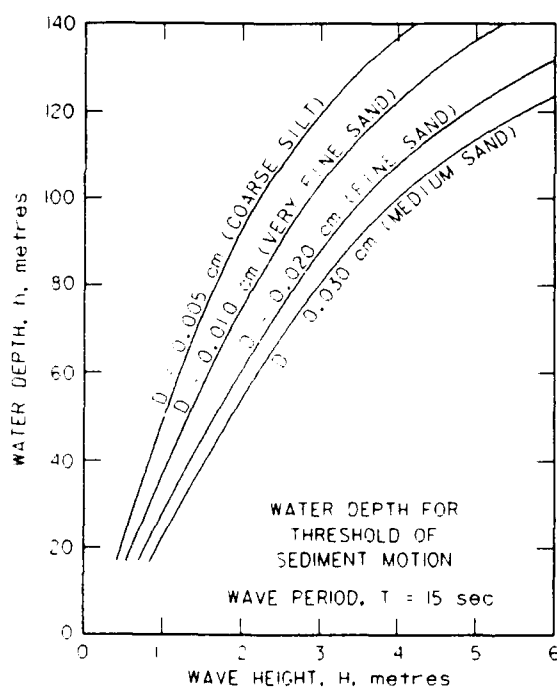


Figure 12. Expected water depth of sediment movement due to surface waves for period $T = 15$ sec and a range of sediment grain sizes and wave heights (after Komar and Miller 1975)

(Figure 14). A somewhat finer grain size might be moved both during the onshore motion and offshore flow but would only shift offshore a small distance during the return orbit since most of the current of the return orbit would not be sufficient to move the grain.

There is considerable evidence that, at least in shallow water, waves alone can produce an onshore sediment transport because of the asymmetry of their orbital motion. As shown in Figure 13, the orbital motion under the crest is of high speed but low duration, whereas the offshore return motion under the trough is of lower speed but longer duration. Even though the surface orbital velocities may be quite high, the velocity decreases very rapidly and becomes very small at depths in excess of 20 m. For instance, a wave with a 5-sec period and a height of 1 m would have an orbital velocity of 100 cm/sec at the surface but only 1 cm/sec at a depth of 30 m. This orbital velocity will cause fine sands to be transported, but not consolidated muds.

Some grain sizes, especially of quartz sands, may be of sufficient size that they are transported only by the stronger onshore orbital motion and are not moved at all by the return offshore flow

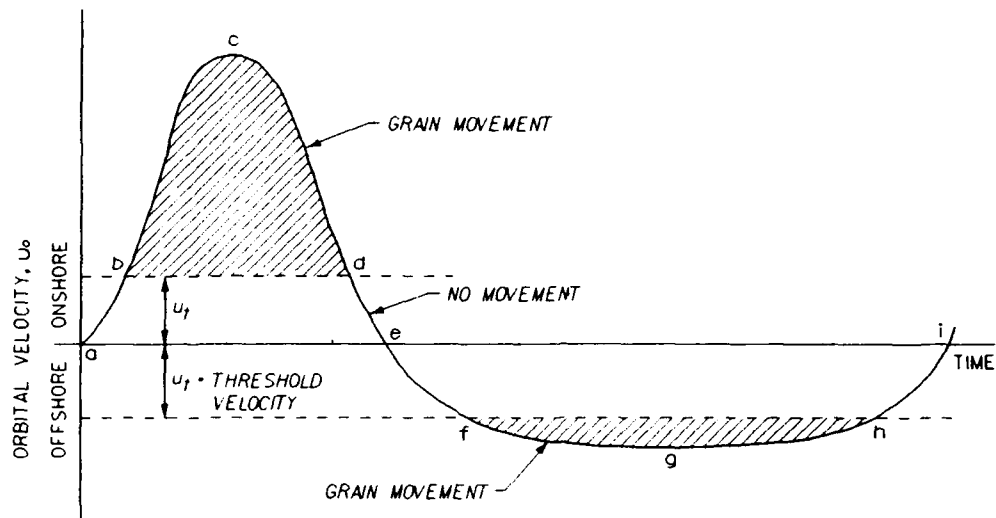


Figure 13. Sediment movement under a near-bottom wave orbital motion (velocity at b under the crest is higher than at e under the trough). This causes a net on-shore movement of certain grain sizes (after Komar 1976)

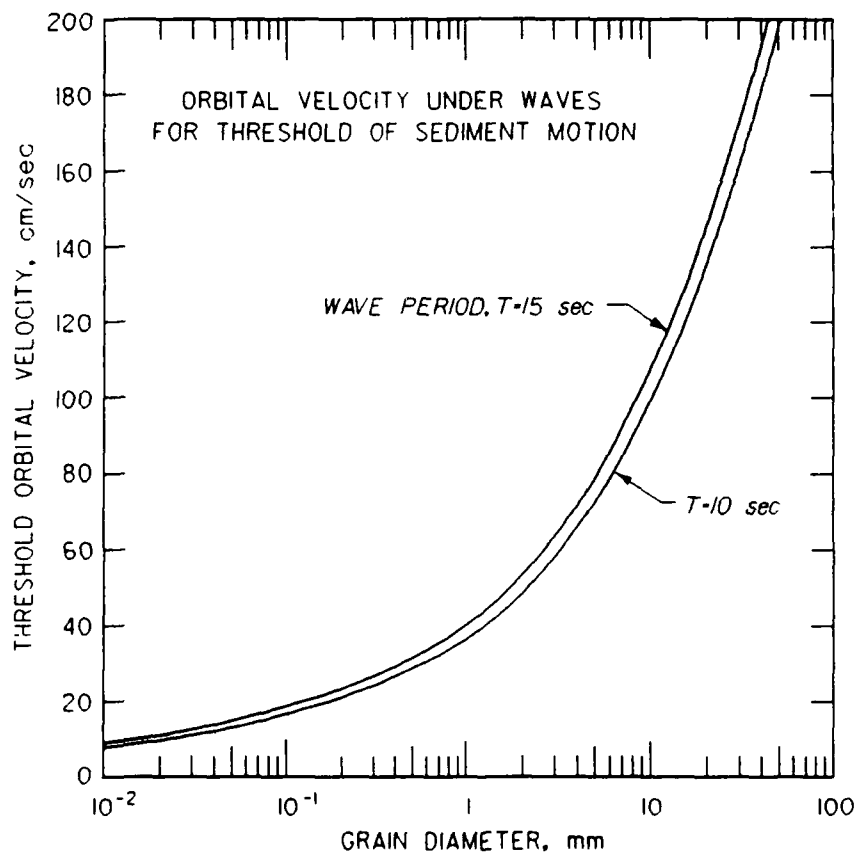


Figure 14. Bottom orbital velocity and wave period (T) necessary for the threshold of sediment motion under waves (after Komar and Miller 1975)

Hence, there would be a net shoreward movement. Actually in nature, the bigger the particle, the more pronounced is the onshore creep (Bagnold 1940). It is conceivable that with an offshore current superimposed on wave motion, fine sediments that are thrown into suspension will be carried offshore while coarser sediments that remain near the bottom are carried onshore. There are records indicating that, on some coasts, sands have been transported onshore from as much as 20 km offshore.

On the other hand, when fine material has been resuspended in nearshore areas, even very low-velocity currents will tend to carry the material shoreward, and if estuaries or harbors are nearby much of the material will be funneled into the estuaries and deposited.

Deposition of silt and some clay will begin at shelf depths where wave surge currents fall below 5 and 10 cm/sec (see Curray 1960). This depth will depend on the exposure of the coast but generally ranges from 20 to 50 m.

Drake (1976) points out that two factors are characteristic of fine-grained particulate matter and tend to greatly increase shelf retention of muds: grain aggregation and interparticle cohesive forces. Shelf suspended sediments, including those derived from dredged material, are always highly aggregated. Aggregates with average diameters in the medium to coarse silt range (31 to 62.5 μ) usually contain hundreds of very fine silt and clay particles bound together by organic matter and van der Waals forces. These aggregates sink much more rapidly than single clay and fine silt particles. The increased settling rate results in a rapid loss of suspended matter from surface waters flowing seaward into near-bottom waters that, in many cases, appear to migrate onshore slowly. Often these particles scavenge pollutants from the water column.

Longshore currents and sediment transport

Longshore currents play an important role in transporting sediments that have been brought shoreward by processes mentioned above. If estuaries occur along the coast, some of these sediments will undoubtedly be carried into the estuary. Longshore currents are generated by breaking waves through two processes that in some places occur together. The first of these is the longshore current caused by waves breaking at an angle to the shoreline; the second is the rip current and its associated longshore currents.

Oblique wave fronts. In most places waves run up the sloping beach at an angle, but their fallback is vertical or normal to the beach (Figure 15). As a result, longshore currents are produced which will transport sediments parallel to the coast. Some of these will be beach sands, but other components may be material dumped at sea and carried shoreward. For the most part these longshore currents occur inside the breaker zone; however, under certain conditions, they occur seaward of this zone as well.

Rip currents. Rip currents are always associated with longshore currents, the cause of which is somewhat more complex than that associated with oblique wave fronts. When waves arrive at the shore with their crests more or less parallel to the shoreline, there is a small lowering of water level just outside the breaker zone while there is a rise of mean water level inside the surf zone. Since it will be higher where the breaking waves are largest, water inside the surf zone will flow along the shore to the areas where the waves are smallest. Thus, the longshore currents converge toward positions of lowest wave breakers where the flow turns seaward as rip currents (Figure 16).

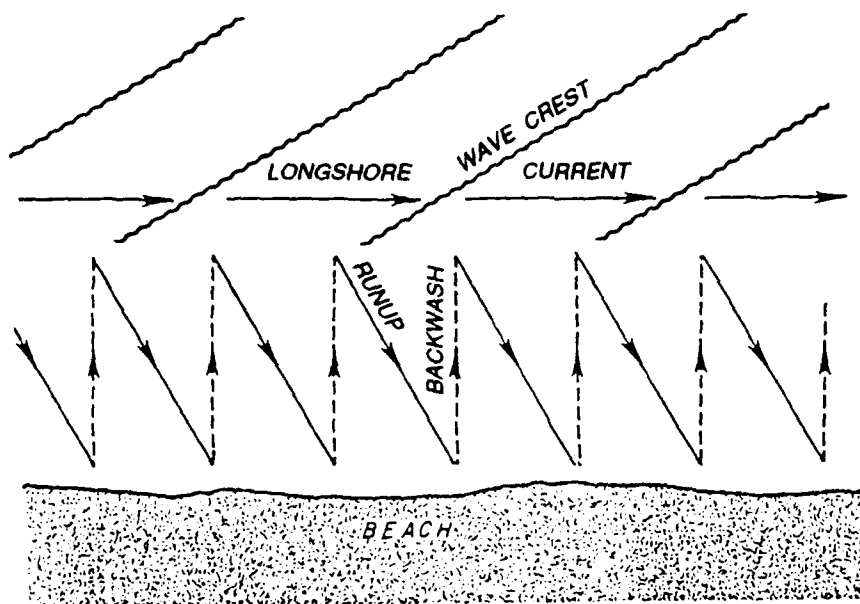


Figure 15. Graphic portrayal of how a wave train approaching the shore at an angle can create a longshore current

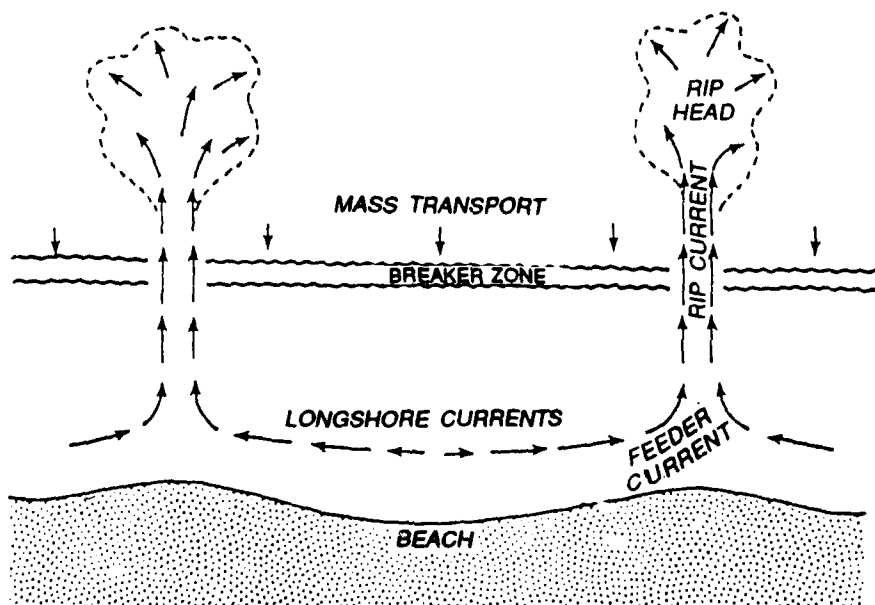


Figure 16. Nearshore cell circulation consisting of feeder longshore currents, rip currents, and a slow mass transport returning water to the surf zone (after Shepard and Inman 1950)

SITE DESIGNATION PROCESS

The components to be considered in selecting and designating ocean disposal sites are:

- a. Evaluation of need for designation of a new site.
- b. Identification of suitable areas for site designation.
- c. Gauging site requirements in relation to dredged material characteristics.
- d. Selection of candidate sites.
- e. Estimation of fate and potential effects of dredged material disposal at candidate sites. Both short- and long-term fates must be estimated.
- f. In light of all the above, evaluation of alternative candidate sites.
- g. Final selection of the new ocean disposal site.

The process may be terminated at any one of the above steps if the data gathered indicate the potential for unacceptable impacts. In terms of alternatives, the process can be terminated if newly acquired data reveal that utilization of a land-based site would be less costly and would have a lesser impact on the total environment.

SCREENING TECHNIQUE FOR LOCATING AN OCEAN DISPOSAL SITE

Description

Above all, site locations should be selected to minimize the interference of disposal activities with other uses of the marine environment, particularly the existing finfisheries and/or shell fisheries and regions of heavy commercial or recreational navigation.

The procedure for designating suitable areas for disposal includes the following tasks.

- a. Define the large-scale ocean region potentially suitable for the ocean disposal site. This is called the Zone of Siting Feasibility (Mathis and Payne 1984). In order to arrive at the final decision as to the Zone's boundaries, one must heed (1) navigational restrictions, (2) political or other jurisdictional boundaries, (3) distance to the edge of the continental shelf, (4) the feasibility of surveillance and monitoring, and (5) the operational and transportation costs.
- b. Having defined the Zone of Siting Feasibility, identify potential sites. To do this, one should prepare base maps of the Zone. Nautical charts available from NOAA/NOS should be used as base maps (available scales range from 1:40,000 to 1:250,000). These can be obtained from local marine supply stores and other sources.
- c. After obtaining and compiling the appropriate data, prepare composite overlay maps for biological resources and areas of incompatible uses (this step can be computerized as noted below). One can generally obtain the needed data from local, state, and Federal government agencies. For instance, information on fishery resources can be obtained from state Fish and Game agencies and NOAA/NMFS fishery centers in Woods Hole, MA; Beaufort, NC; La Jolla, CA; and Seattle, WA (see also Table 24).

Table 24
Sources of Information for Uses of the Ocean

Use	Sources of Information
Recreational	
Beaches	NOAA
Local, state, and national parks	Sea Grant agencies
Boating and marinas	State agencies
Swimming and SCUBA diving	Diving clubs
Surfing and windsurfing	Chambers of Commerce
Cultural and historical sites	
Archeological sites	NOAA/SHPO
Shipwrecks	Sea Grant agencies/SHPO
	Local museums
	Historical societies
	Smithsonian Institution
Navigation	
Commercial shipping lanes	NOAA/NOS charts
Military shipping routes and exclusion zones	US Navy
Scientific research	NOAA
	Minerals Management Service (MMS)
	National Science Foundation
	Local universities
Commercial and industrial	
Undersea pipes and cables	NOAA/NOS charts
Mineral resources	State agencies and MMS
Oil and gas resources	State agencies and MMS
Sand and gravel resources	MMS
Undersea mining areas	MMS
Industrial and municipal water intakes	USEPA

Having accomplished these tasks, one can easily determine if there are suitable sub-areas for site selection and designation. Although unlikely, if no subareas can be identified as suitable for siting a disposal site, one can enlarge the geographical region under consideration. If this is infeasible, one will be required to reevaluate alternative land-based options for disposal.

The screening technique for selecting the location of a dredged material disposal site involves a methodical, step-by-step elimination of unsuitable areas of the seafloor, based on economic, aesthetic, recreational, and environmental criteria, until only acceptable areas for its location remain (Pequegnat 1984). The unsuitable areas for whatever reason will be screened out and darkened on the navigation chart. When all such areas have been blocked out, the potential site areas will stand out in bold relief.

Constraints in Applying the Technique

It is advisable at the outset to arrive at the maximum haul distance from the harbor entrance that is acceptable for reasons of cost. Assuming the haul distance to be 20 km, a tangential arc of this radius is scribed on a navigation chart. The area between the arc and the harbor entrance is the Zone of Siting Feasibility (Mathis and Payne 1984). For safety reasons it may be advisable (not always) to screen out shipping fairways (Figure 17). Also, every effort should be made to find an acceptable location to the right of the harbor exit, as noted above.

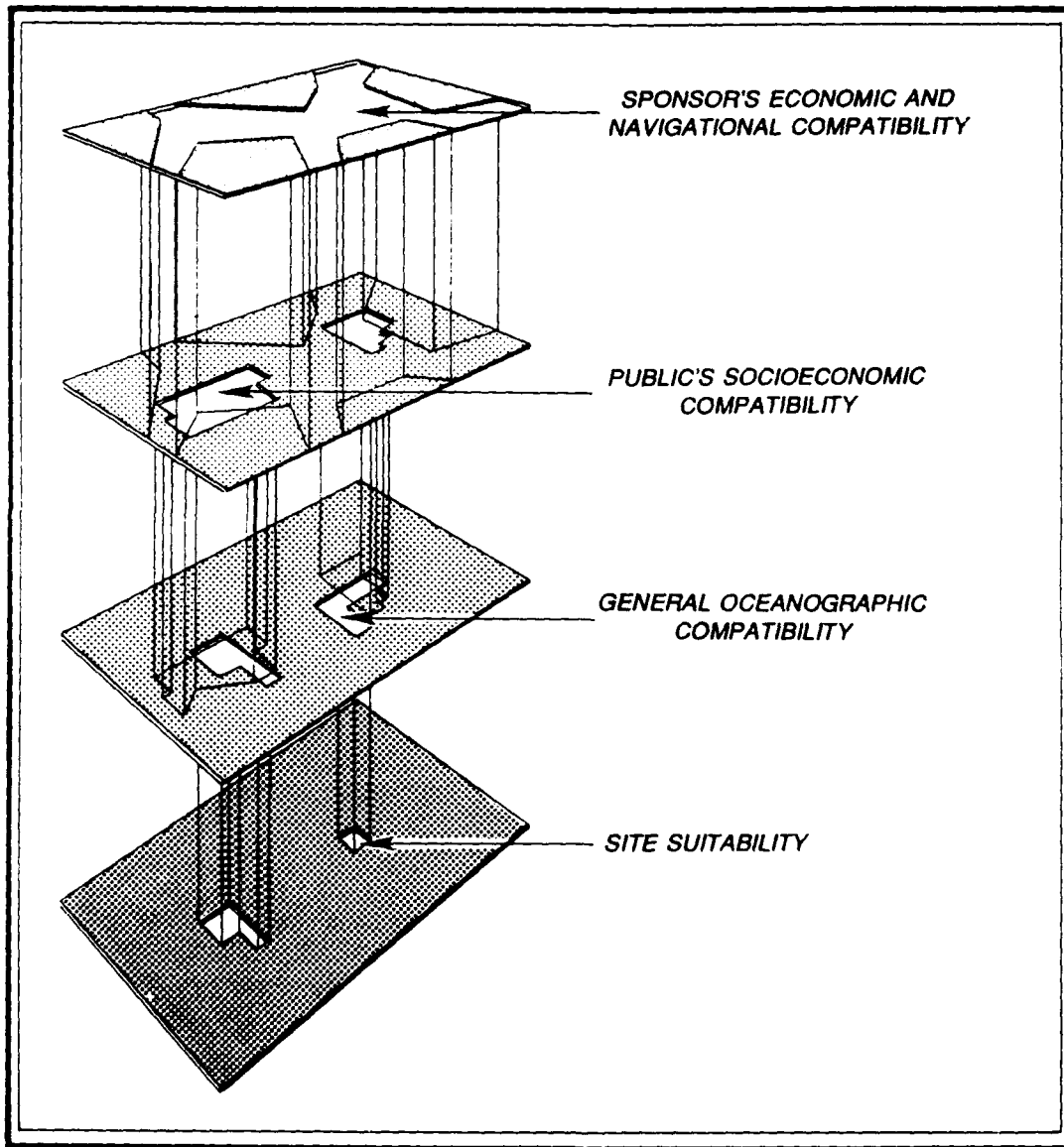


Figure 17. General representation of the screening (sieve) technique for siting. Unsuitable areas are eliminated step-by-step until the small white site areas stand out very clearly

Assuming a thorough review of the relevant literature and consultations with appropriate public officials and interested environmental and SCUBA diving groups have been completed, and mindful of USEPA's specific criteria for site selection, we shall proceed to scribe on the chart (Figure 18) the locations of such features as

- a. Commercial fishing and shellfishing grounds.
- b. Recreational fishing and diving reefs.
- c. Spawning grounds of important species and their food organisms.
- d. Migration routes of finfish or shellfish including passes into estuaries.
- e. Archeological features.
- f. Beaches and other amenities.
- g. Endangered species.

Buffer Zones

Since we can assume that bottom currents often attain speeds up to 0.5 knot and that much of the dredged material except the very finest would settle out in less than 4 hr, we should protect any amenity and living resource by establishing the adjacent edge of the disposal site to be no closer than 2 nautical miles to the amenity, since this is the distance that a 0.5-knot current would travel in 4 hr (1 knot = 1 nautical mile per hour). This arbitrary number may be modified through the use of appropriate models.

Accordingly, these amenities and their buffer zones are then screened out by darkening (Figure 19).

The unscreened areas that now appear on the chart are suitable for locating the disposal site. At this point the site will generally be placed as far downcurrent from the estuary mouth as feasible to minimize transport of the material back into the estuary. Then much more detailed parameters such as sediment type can be given consideration in making the final choice.

This technique is amenable to computer treatment. In fact, seven CE Districts have established effective programs (among them New England and Portland).

COMPUTERIZED SYSTEM FOR SITE DESIGNATION

The Portland District has made very effective use of the screening technique by using a computerized geographic information system (GIS) to duplicate the overlay process of screening the zone of siting feasibility.* This GIS approach lends great flexibility to the process and was used by Portland District at Yaquina Bay and the mouth of the Columbia River, yielding results similar to what had been obtained using the manual overlay system.

The GIS is a two-dimensional equivalent of a computerized database management system in that map-based spatial data can be inputted to a computer system for mathematical

* W. V. Clement and P. E. Orlowski. 1984. Geographic information system applications at the Portland District (unpublished), US Army Engineer District, Portland, OR.

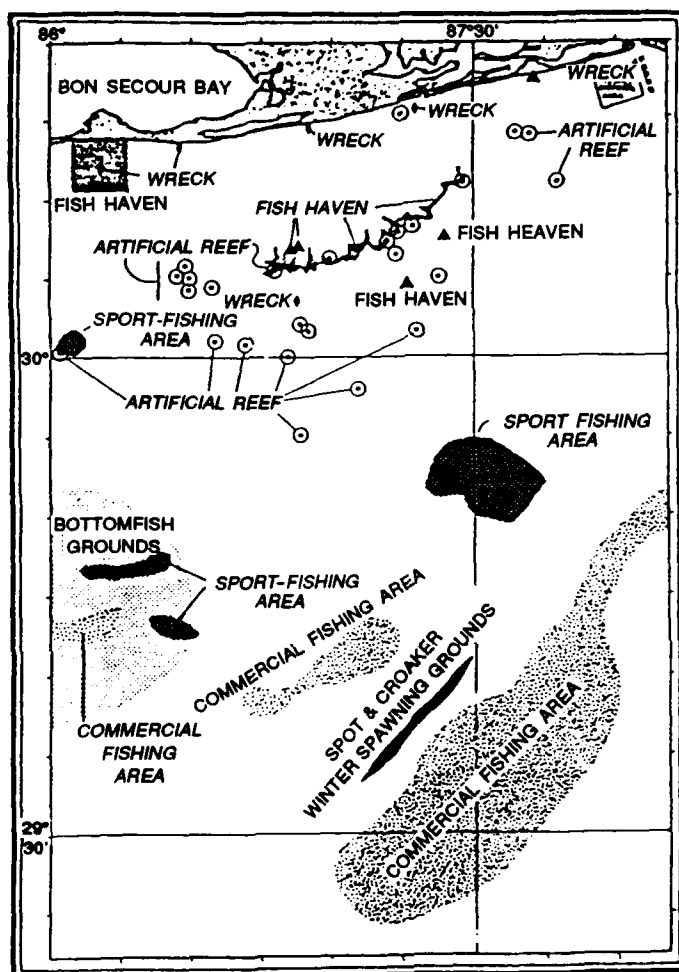


Figure 18. Plot of sensitive environmental areas off Mobile Bay, AL, that must be protected by buffer zones and screened out by the screening technique, as shown in Figure 17

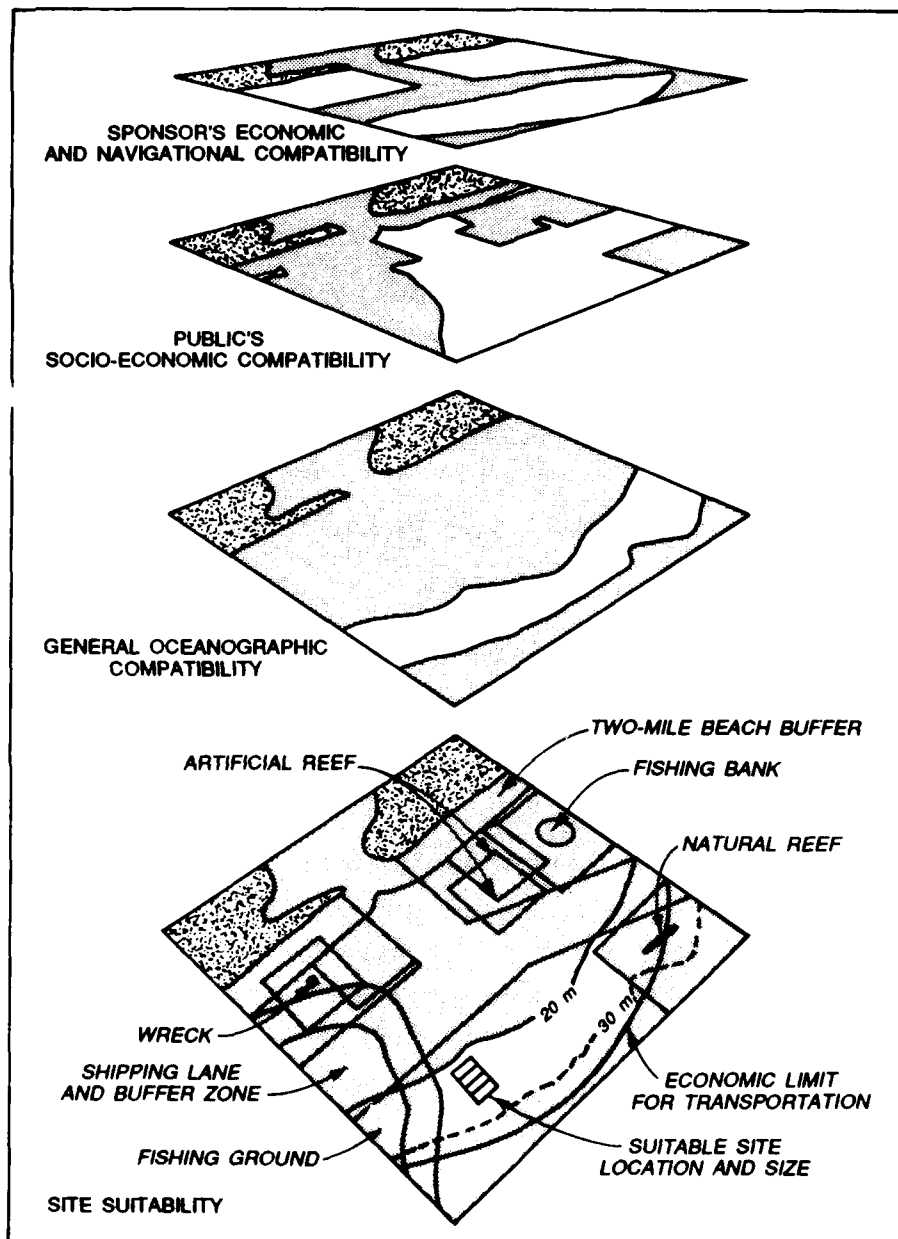


Figure 19. Application of the screening technique to siting a dredged material disposal site. Top figure shows the screened out area beyond the haul distance arc and the shipping fairways. The second figure shows areas screened out because of nature preserves and public beaches. The third figure shows depth compatibility. The final figure shows all the screened out areas and the placement of the site

analyses and displays. In the approach, base maps are created and divided into a grid having a predetermined number of rows and columns, creating cells of known size and known geographic coordinates. Response or input variables (environmental factors) are selected and assigned class values; each variable is geographically referenced to the base map, creating "image files." The seive or screening method outlined by Pequegnat (1984) is essentially an overlay process in which the occurrence of any variable on any of the image files will screen out its corresponding areas on the final image. The automated GIS enhances this process in that each input variable on each image file will have its own class value. During the overlay analysis, the highest class value from any other image file will override the lower class values from any other image file, leaving only the highest class values (highest impact) on the final image. Additionally, the variables can be easily indexed, weighted through recoding or combined to show which areas have more than one variable of concern. There is no restriction on the number of image files that can be combined or the manner in which they can be combined. A GIS can provide an expeditious replacement for the manual overlay techniques, permitting greater analysis flexibility and improved graphic output.

DEALING WITH EXISTING SITES

Some of the dredged material sites that are now in use in US waters may not meet the above specifications, in part because they are small and located in very shallow water. Clearly they will not be abandoned in the near future, but very likely some should be eliminated and more appropriate sites established. A few guidelines for deciding whether a substandard site should be replaced would certainly include

- a. Whether the site is located in an open high-energy environment or in a sheltered part of the coastal environment where wave forces normally are moderate.
- b. Whether the site receives maintenance dredged material from industrial waterways.
- c. Whether the site has received maintenance dredged material during the past 5 years without observable environmental impact and **without public protest**.
- d. Whether there are plans to increase the volumes of material to be disposed in the site primarily because of new work or increased maintenance needs.

RELATED LITERATURE

Much of the foregoing is based upon Pequegnat (1984). More detailed discussions can be found in "General Approach to Designation Studies for Ocean Dredged Material Disposal Sites" (USEPA/USACE 1984). One can find here a description of the Zone of Siting Feasibility. Pequegnat (1984) intended the concept to apply only to haul distances and thus to the economics of the project. The discussion in the joint EPA/CE manual addresses many other factors, including logistics, need to restore navigation in emergencies, dredging methods, textural compatibility, and monitoring feasibility. A brief compendium of the screening technique can be found in "Guidance for Designation of Ocean Sites for Dredged Material Disposal" by Mathis and Payne (1984). A much longer and inclusive document entitled "Ocean Dumping Site Designation Handbook for Dredged Material" was produced for the Office of Marine and Estuarine Protection of USEPA in September 1986 by Science Applications International Corporation.

PART VI: SELECTION OF VARIABLES TO BE MEASURED IN THE FIELD FOR SITE SELECTION AND DESIGNATION

GENERAL

Selection of the oceanographic variables or parameters that should be a part of the field survey of a dredged material disposal site, as well as those that should not be included, requires that consideration be given to the several uses that will be made of the data generated by the survey. The principal applications of the data that are discussed in this part include:

- a. First, some of the survey data may help in the siting process to confirm that a potential new site is a good one.
- b. The survey data must also fill the needs of adequate environmental documentation for final designation of ocean dredged material sites presently in existence.
- c. Survey data will be used to support designation of new ocean dredged material disposal sites insofar as they satisfy the general and specific criteria for site selection.
- d. The data should be collected and analyzed with methods of accepted applicability to facilitate use in any future monitoring. Recommended methods for physical and/or chemical analyses of samples are provided in Appendix C. To do this may require consideration of Part 228.9 of the 1977 Regulations and Criteria.
- e. Finally, the data can be used to support documents prepared by the CE for USEPA review of permits to transport and dispose dredged material in the ocean, as specified in Section 103(c) of MPRSA. Data, therefore, must meet some of the stipulations of Section 102(a) of MPRSA.

The stipulations of the Act and the Regulations and Criteria will provide the basis for selecting most of the variables to be measured in the field survey. These will be discussed in detail in ensuing sections of this chapter. Before that, however, it will be useful to set forth the philosophy that undergirds the selection of variables to be included as well as those not to be included in the survey.

SURVEY PHILOSOPHY

Oceanographic surveys can include a wide variety of measurements in biology, chemistry, geology, meteorology, and physics. The purpose of this part is to present an appropriate selection of those variables that will contribute most to preparation of adequate environmental documentation for site designation, make a good impact-monitoring program, or meet the criteria applying to the issuance of a dumping permit. Each unnecessary parameter included in the survey will take time and effort that can only boost costs unnecessarily.

Several guidelines have been established that have shaped the decisions in regard to the constitution of the survey. First, the designation of a disposal site does not assume that dumping will or will not have an effect on the biota within the site. The emphasis is placed upon avoidance of significant impacts to the environment and its biota beyond the site boundaries. It follows from this that one must be concerned with movements of the water column that could carry some constituents of the dredged material beyond the

boundaries of the legal site. This would seem to imply that a study of currents by means of current meter arrays must be called for, but such is not necessarily the case. Most present dredged material disposal sites are so shallow that water movements are determinable from wind, swell, sediment, and topographic data, all of which should be available from published sources.

A limited amount of current meter work may be called for at some interim and new sites, as will be discussed later in this part. It should be pointed out here, however, to those persons who may feel that currents should be studied at new sites in order to predict the movement of disposed dredged material, that there is a difference between current and water circulation. The latter requires much more study to determine than the former. Yet it is the circulation flow which will carry that fine part of the dredged material prior to settlement or after resuspension by storms. Very likely as much as a year's study would be required to yield data that would add much to the present conception of the typical flow on the continental shelf of a given region.

The second guideline is that the survey will place less emphasis upon the biota of the water column than upon that of the bottom. Physicochemical data on the water column will characterize the site, define the mixing zone, and establish ambient levels of some pollutants. Biological evaluations of water-column impacts are not generally advocated because it has become accepted that dredged material impacts here are minimal and transitory. Contrariwise, emphasis is placed upon the evaluation of the sediments and benthos at the disposal site environs. Finally, selection of indispensable variables for the ocean survey has been guided by the regulations issued by the Council on Environmental Quality (29 November 1978, **Federal Register**) delineating adequate environmental documentation and stressing the need to describe the process by which an ocean-disposal decision is reached by the CE or USEPA.

LEGAL AND REGULATORY REQUIREMENTS

Environmental Documentation for Designation of Interim and New Sites

The Council on Environmental Quality published in the 29 November 1978 **Federal Register** the final regulations implementing the procedural provisions of the National Environmental Policy Act. Three parts of these regulations are directly related to the nature of the ocean survey to be recommended in this part. Related to preparation of environmental documentation, these are

- a. Emphasis upon alternatives including the proposed action. It is expected that environmental documentation will evaluate the environmental impacts of the proposal and all reasonable alternatives, which would minimize adverse impacts of the human environment. Therefore, the survey must determine what is present to be impacted.
- b. A succinct description of the affected environment, including the area outside the disposal site that may be modified by direct and indirect effects of the disposal process.
- c. An analysis of significant impacts of the disposal and, where appropriate, supplying practicable means of mitigating adverse environmental impacts (40 CFR 1502.16(h)).

Basis for Programs to Monitor and Evaluate Impacts

Part 228.9 of the 1977 Regulations and Criteria (pp 2483-84) allows establishment of a monitoring program that will provide the basis for evaluating the impact of disposal on the marine environment. We would emphasize that it is generally not the purpose of designation surveys to provide either a basis or a baseline for monitoring. Designation surveys are for the sole purpose of designating a disposal site, whereas monitoring needs will be highly dependent upon the material to be disposed, management actions, and other considerations. We include monitoring considerations in this section only to reinforce the concept that techniques and procedures used to gather data during designation be such as to be compatible with any future monitoring needs. Recent modifications of monitoring programs applied to the disposal of dredged material are discussed in detail in the Part IX. Techniques used in these programs are described and evaluated in that part. The discussion of monitoring in this section is to give consideration to all of the variables that have been and, in some cases, are still being used in a variety of monitoring programs.

In selecting variables that should be included in the monitoring program, the authors have been guided by the possible effects from the disposal of dredged material. Because the monitoring program's success depends upon hypothesis testing, quantifiable baseline data are required. Conditions that the monitoring effort should be concerned with are the following:

- a. Absence from the disposal site vicinity of biota characteristic of the general area. This should apply particularly to the extended impact zone (see Part I).
- b. Progressive, nonseasonal adverse changes in composition or numbers of demersal fishes and/or benthic macroinfauna near the disposal site that are potentially attributable to the effects of dredged material disposed within the site. In some cases one may elect to use the BRAT system or sediment profiling camera (as explained in Part IX) to evaluate these conditions.
- c. Progressive, nonseasonal adverse changes in the characteristics and inclusions of the sediments (in special cases of the water column, as well) near the disposal site, when it is suspected that the changes are attributable to the effects of materials disposed of at the site. The basis for this could be established by evaluation of the physicochemical characteristics of the disposed sediments removed from the dredging site and those in the disposal site environs.
- d. Dredged material has or has not moved into estuaries, marine sanctuaries, productive fin fishery or shell fishery areas, or onto beaches or shorelines or become a navigation hazard. If a disposal site has been carefully placed at appropriate distances away from amenities and resources of limited geographic distribution in accordance with known patterns of water circulation and storm disruptions, this consideration should not present special problems.
- e. Bioaccumulation in selected marine biota of chemical pollutants and/or human pathogens. The principal concerns are with burrowing or sedentary species that are either components of the diet of human beings or are the prey of such species. Tissue analyses are usually done upon species that are top carnivores, and interest is centered in muscle tissue because muscle tissue constitutes a major part of the edible portion and is the tissue from which depuration is most difficult.

Supporting Data for USEPA Approval of Permit Requests

Some ocean survey data may be provided by the CE to the USEPA (Regional Administrators) for review of the transport and disposal of dredged material in the ocean, as specified in Section 103(c) of the Act. During such review, the USEPA may be expected to bring to bear those environmental considerations listed in Section 102(a) of the Act, to wit:

- a. The effect of such disposal on human health and welfare, including economic, aesthetic, and recreational values.
- b. The effect of such disposal on fisheries resources, plankton, fish, shellfish, wildlife, shorelines, and beaches.
- c. As noted above, the effect of such disposal on marine ecosystems, particularly with respect to:
 - (1) Transfer, concentration, and dispersion of such material and its by-products through biological, physical, and chemical processes.
 - (2) Potential changes in marine ecosystem diversity, productivity, and stability.
 - (3) Species and community population dynamics.
- d. The persistence and permanence of the effects of the disposal.
- e. The effect of disposal-particular volumes and concentrations of such materials.
- f. Appropriate locations and methods of disposal or recycling including land-based alternatives and the probable impact of requiring use of such alternate locations or methods upon considerations affecting the public interest.
- g. The effect of alternate uses of oceans, such as scientific study, fishing, and other living resource exploitation and nonliving resource exploitation.

ANALYSIS OF OCEAN SURVEY PLAN

Constituent and Deleted Variables

The study plan presented in Part 228.13 of the 1977 Regulations and Criteria is not directly applicable to dredged material disposal sites. It was designed primarily to apply to disposal sites for municipal and industrial wastes, which are of relatively low density or have important constituents that are. It was expected that some constituents of most of the wastes involved were either toxic or would produce some adverse unacceptable changes in the water column. Also, the plan was expected to be applied to disposal sites that were by comparison large and located in deep water. For these reasons then, the 228.13 study plan places considerable emphasis upon biotal measurements in the water column and, because of size and depth, calls for the mounting of many stations and the taking of numerous discrete samples on the vertical axis.

If, then, the present recommended survey guide for dredged material sites seems limited by comparison, the reasons are related to the nature of most dredged material and the sites at which it is disposed. More specifically, it is expected that:

- a. Most dredged material has a high density factor and will then sink rather rapidly through the water column. Moreover, those constituents that sink less rapidly, such

as clay particles, will tend to accumulate at interfaces (e.g., thermoclines and haloclines) where their impact on the biota is minimal.

- b. Most dredged material disposed in the ocean is relatively inert and in other ways relatively harmless to marine ecosystems. There are special exceptions to this statement, but such materials are generally dealt with in special ways.
- c. As noted in Part II, the majority of dredged material sites are small; hence, a small number of intrasite stations are required.
- d. The majority of sites are located in shallow water; hence, a small number, if any, of extra-site stations and vertical samples are required.

The variables or parameters appearing in Part 228.13 of the 1977 Regulations and Criteria are generic and were designed to address a wide variety of materials. Those which appear to be applicable for dredged material are presented in Table 25; those not felt to be applicable are presented in Table 26. For the reader's convenience, all parameters, whether recommended or not, are discussed hereinafter in order of their appearance in Part 228.13(a-f) of the 1977 Regulations and Criteria.

Timing (228.13a)

In sites having extremely high or low environmental variability through time, a single survey will usually be adequate to characterize any resources of limited geographic distribution which may be present. Where there are marked differences in water temperature at a site, one survey should be done in the warm period and the other in the cold period. Where the site is influenced by substantial riverine flow, sampling should be done in the high-and low-water periods. Other factors, such as high and low sediment input, hypersalinity, and hyposalinity, may need to be considered.

Duration (228.13b)

The ocean survey recommended in this guide can be carried out at most dredged material sites in 2 to 4 days, depending on size and depth.

Numbers and Locations of Sampling Stations

This is an important consideration that is discussed more fully in Part I. It is to be noted, however, that the minimum number of stations recommended for EIS preparation is six and the maximum is nine, but the number will have to be increased substantially when the extended impact zone expands toward a valuable resource.

MEASUREMENTS IN THE WATER COLUMN AT AND NEAR THE DISPOSAL SITE

Water Quality Parameters

Because temperature, salinity, and oxygen data can provide information on water flow, it is essential that the following variables be measured at all stations:

- a. Temperature-depth structure.

- b. Salinity-depth structure.
- c. Dissolved oxygen profile.

Table 25
Oceanographic Variables Applicable for
Ocean Surveys for Site Characterization and
Designation of Dredged Material Disposal Sites

<u>Variables</u>	<u>Site Characterization</u>
Water Column Characteristics	
Temp./salinity/depth	All stations
Dissolved oxygen	All stations
Turbidity	All stations
Contaminants	Center stations
Dissolved Hg, Cd, Pb, Cu	and proximal
High molecular weight hydrocarbons	upstream
PCBs	station
Chlorinated pesticides	
Current meter	Site center (repeat during survey)
Sediment Characteristics	
Gross bathymetry	Cover the site and environs
Grain size and human debris	All meiofauna cores--first two macroin- faunal cores
Total organic carbon (TOC)	All stations
Contaminants	All stations
Metals: Hg, Cd, Pb, and Cu	
High molecular weight hydrocarbons	
Oil and grease	
PCBs	
Chlorinated pesticides	
Biotal Characteristics	
Macroinfauna	All stations
Meiofauna	All stations
Macroepifauna	3 stations
Bioaccumulation (tissues)	(1 in and 2 outside)
2 spp. for Hg, Cd, Pb, Cu, PCBs, petroleum hydrocarbons, pesticides	
Bioaccumulation	--
Introduced species	
Indigenous species (analysis of muscle for above contaminants and liver for enzymes--optional)	

Table 26
Variables Inapplicable for Ocean Surveys
for Site Characterization and Designation
of Dredged Material Disposal Sites

Water Column/Pelagic Environment
Contaminants
Metals: Extensive list in Regulations Criteria
Multiple, vertical stations
Extensive current meter survey
Total organic carbon
pH
Inorganic nutrients
Chlorophyll <i>a</i>
Biota
Zooplankton tows night and day
Phytoplankton water samples
Contaminants in zooplankton
Sediment Bed/Benthic Environment
Sediments
Mineralogy
Settling rates
Contaminants
Metals: Extensive list
Biota
Microbenthos

Low dissolved oxygen values often occur naturally in bottom waters of the inner shelf in summer and fall; enough data should be on hand to clear dredged material as the cause.

The following variables should be measured only at the station nearest to the center of the site. (A discussion of the reasons for these chemical measurements is given in the section "Chemical Contaminants in the Sediments.")

- a. Trace metals.
 - (1) Dissolved Hg (separate water sample).
 - (2) Dissolved Cd and Pb.
- b. Other Annex I substances: PCBs, chlorinated pesticides, and high molecular weight petroleum hydrocarbons.
- c. Turbidity measured as a profile from surface to the bottom. It may be necessary to carry out this investigation along the axis of the extended impact zone.

It is expected that most Corps Districts and USEPA Regional offices will have data on hand from past studies as to background levels of Section 227.6 substances on interim sites. If not, and for new sites, available information must be obtained from other agencies or the open literature.

Measurements of temperature against depth, which is usually done by means of a recording probe system, are required to ascertain the presence or absence of a **thermocline**

(zone of maximum rate of decrease of temperature with increasing depth). This will establish the vertical thickness of the mixed layer, a consideration that is important to calculations of the limiting permissible concentration, as discussed in Part 227.27 of the Regulations and Criteria. At most dredged material disposal sites the thermocline will be seasonal (not permanent) due to shallow depth. When coupled with salinity data, one may calculate changes of density with depth. Where density is increasing rapidly with depth, a **pycnocline** is observed. This may correspond in position with the thermocline, since density of the open ocean is determined primarily by temperature. When density of the water column increases steadily from the surface to the bottom, it may be deduced that vertical movement and vertical mixing of the water and its constituents are minimal.

Measurements of dissolved oxygen (DO) are not as important as the above parameters, but determinations should be made, especially near the bottom in sites that are used frequently. One might expect some temporary reduction of DO near the bottom if the dredged material was recently disposed and had a high biochemical oxygen demand (BOD).

Turbidity increases of a temporary type are always associated with the dredging/disposal process, especially as clay-size particles may remain aloft in the water column for long periods of time. It is well known, however, that some coastal regions have chronically turbid water near the bottom (the nepheloid layer), which is not associated with dredging. In fact it is more likely associated with shrimping and trawling for bottom fish. Therefore, it is important to obtain some baseline data on turbidity during an appropriate interval after disposal.

Sampling Requirements for Water Quality

Since the majority of dredged material disposal sites are very shallow, it will not be necessary to take many vertical samples for water quality determinations. The following guides may be followed:

- a. If the site is shallow, no seasonal thermocline is present, and the column has about the same temperature at the bottom and at the surface (isothermal), then only one sample need be taken **near the bottom**.
- b. If the site is shallow and a seasonal thermocline is present, one sample should be taken just above the thermocline and one sample near the bottom.
- c. Sites of intermediate depth will require three samples--one above the thermocline, one in the thermocline, and one near the bottom.
- d. Deep sites will require the three samples for intermediate depths (as in c above) plus a fourth sample between the thermocline and the bottom sample.

Water Column Biota

Sampling of the pelagic biota in the water column is not recommended in this guide, simply because it is expected that it will suffer only transitory impacts from the disposal of dredged material. The density of the bulk of dredged material disposed in the ocean is so high that it moves quickly through the thermocline. Moreover, the water and its biotic contents impacted by a discrete disposal from, say, a hopper dredge, will soon move out of the area and will not be available for subsequent sampling. It is anticipated that

available literature on the pelagic biota of regions containing ocean disposal sites will be sufficient for adequate environmental documentation. Scientists consulted during preparation of the guide agreed that the pelagic biota cannot be quantified with sufficient precision to justify its use for monitoring. This applies particularly to the phytoplankton, the distribution of which is patchy in both time and space. Thus, it is possible to obtain discrete phytoplankton samples in early winter that have a higher cell count than those of spring or early summer during a phytoplankton peak. This high uncertainty factor renders the phytoplankton useless as a quantitative monitoring tool. In some regards, however, there may be special reasons why it may be necessary to allocate some survey time to this parameter. For instance, there is continuing interest in the role that the dinoflagellate *Ceratium tripos* may play in the appearance of very low dissolved oxygen levels in the waters on the mid-Atlantic shelf. In such cases, it is suggested that one take an oblique net tow from below the thermocline to the surface near the center of the site. Counts would then be made of the three most numerous species. It should be pointed out that *C. tripos* is found along all US coasts, where it may undergo blooms that are somehow related to lowered oxygen levels at the bottom.

MEASUREMENTS OF THE BENTHIC REGION

Gross Bathymetry

To sample some parameters effectively, the Chief Scientist must have knowledge of the bottom topography in and around the site. This information can be gained with the ship's recording Fathometer by crossing the site in a systematic way and plotting the results on graph paper (Figure 20).

Several tracks (probably eight) should be made across the site and environs more or less perpendicular to shore and to the axis of the longshore current. In the case of a site containing a particular topographic feature, the tracks should be made perpendicular to the axis of the topographic feature regardless of its orientation to the shoreline. On each pass the heading and estimated speed of the ship should be marked on each trackline. A good starting point would be a mile outside the site, as shown in Figure 20. The number of transects across the site proper will be dependent upon the degree of irregularity of the bottom. It matters little whether the site is square, round, or rectangular.

As indicated above, two critical considerations in conducting a good bathymetric survey of a disposal site are the spacing between tracks and the length of the lines outside the site. If one has available very good sounding-positioning equipment, it should be possible to run parallel transects that are 100 ft or less apart. The data derived from such a precise survey will permit computer development of a 3-D model of the mound and calculation of the volume of dredged material contained in a mound.

If the presence of resources of limited geographic distribution requires a very precise image of the disposal site, it will be necessary to use one of the computer-integrated systems noted below. As a general rule, this will be very unlikely.

- a. Scanning sonar--based upon the same mechanisms as the ordinary echo sounder, except that it employs a rotating head that gives a continuous signal and cross section of the site at right angles to the course of the boat. This 500-kHz system can be used on the majority of US dredged material disposal sites in spite of the fact that

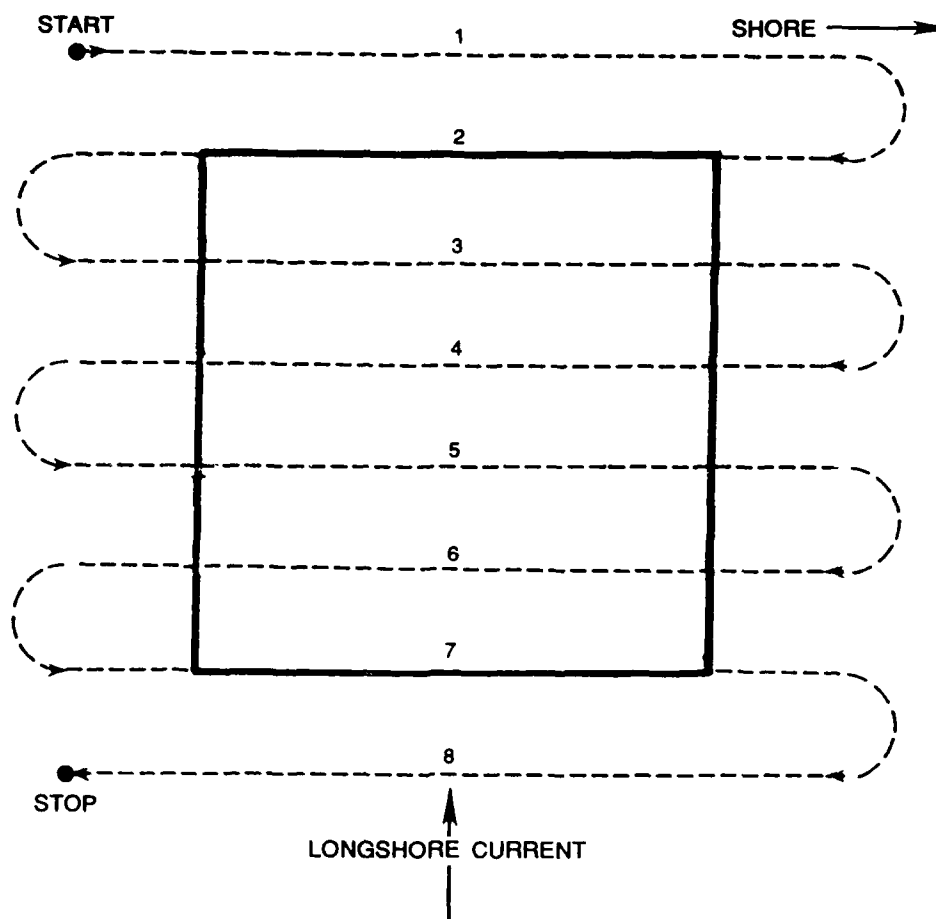


Figure 20. Sample path plan for Fathometer tracks across disposal site

its range is no more than 40 m vertically and horizontally. If the boat is pitching and/or rolling, the returns produce recording aberrations that destroy the value of such a high-resolution system.

- b. Swath surveying--employs a floating array of transducers that are usually pushed ahead of the boat. The signal from each transducer is recorded separately. In some cases, the scanning transducer beam is from side to side. These systems are limited to use over shallow sites, but the ability of onboard computers to integrate the data inputs, which can be displayed in various formats, gives a very detailed conception of what the fate of disposed dredged material has been.
- c. Side-scan sonar--often used to map the physical characteristics of the seafloor and is especially useful in characterizing a new site. However, if one employs a 500-kHz system, it is possible to discriminate between grain sizes of sediments. Thus, it is possible to distinguish the edge of the cap over polluted material and thereby determine whether capping has been complete or whether an older cap has retained its integrity. If one wishes to obtain an overview of the nature of the seafloor, a lower frequency of 100 kHz is employed. Side-scan systems are simple, having a

"fish" containing a pair of transducers that is towed by a conducting cable. The signals are carried over the cable to a shipboard recorder that integrates the information and prints a record of bottom irregularities. Those unfamiliar with side-scan records must have some instruction before use can be made of the images.

- d. Subbottom seismic systems--employ powerful low-frequency signals to penetrate the seafloor and bounce back differentially from various layers of the sediments that exhibit different acoustical impedances. These surveys are appropriate if one needs to determine the extent to which compaction and/or subsidence or both contribute to estimates of losses of material from the site. Tavolaro (1987) estimated that during clamshell dredging, additions of water increased the volume of hauled material from 7 to 36 percent over the excavated volume. One should anticipate this much loss as compaction expels accessory and even pore water from any substantial mounding.

Grain Size Analyses

The grain size analysis is a very important parameter, because it can be used to exclude material from further testing. Hence, sieve data on granulometry must be taken during the initial survey of a new site. It is imperative that the samples are taken in a uniform manner. For instance, the length of the core that is used for granulometry can markedly affect the outcome of the analysis.

Part 227.13 (b,3,i) of the 1977 Regulations and Criteria states, regarding exclusions:

The material proposed for dumping is substantially the same as the substrate at the proposed disposal site.

The surficial sediments down to the depth of penetration of the bulk of the macroinfauna should be sampled. It is suggested here that an average depth of 10 cm is sufficient. It is probably true that in sediments that are predominantly clay, most of the infauna live in the top 5 cm and penetrate to 15 cm or beyond only when the sand component predominates.

Chemical Contaminants in the Sediments

Metals

Although only two heavy metals, viz. Hg and Cd, are mentioned in Annex I of the International Convention, it is advocated that four metals be investigated in the designation survey. Lead (Pb) is added because it is toxic and because it indicates how much contamination of the seabed is entering from the atmosphere (lead coming from the inclusion of tetraethyl lead in some motor fuels). A comparison between the lead content of the sediments of the disposal site and control area will offer some insights on this point. Several advisors have advocated analyzing sediments for copper (Cu) because of its ecological importance.

There may be divergence of opinion among scientific and regulatory personnel on how sediment samples should be prepared for metal analysis, but the suggestion is made here that two methods be selected over the others. Since the major concern of metals in the sediment is whether or not a sediment-ingesting organism can mobilize the metals or the seawater can elutriate them, analyses to evaluate those two processes are preferred. The

pH in the gut of marine invertebrates ranges usually from slightly acid to slightly alkaline, and so a 0.1 N HCl leach is recommended. The short-term impacts of dredged material disposal can be estimated by seawater elutriation.

The other alternatives, total dissolution of the sediment with strong acids or a 1 N to 5 N HNO₃ leach, are not recommended because they are more likely to give a high reading based on total metal content of the sediment rather than the metals available to the ecosystem.

It is recommended that 80 percent of the sediment samples be treated by seawater elutriation and the remainder by 0.1 N HCl. The sediment samples for metal analysis will be removed from the box corer by means of hand-inserted plastic core liner tubing that has an inside diameter (i.d.) of 3.5 cm. Except in special cases, a core length of 5 cm is recommended. A separate sample is required for Hg (at least 50 g); the other metals are analyzed from the second sample. Samples can be freeze dried with the understanding that this procedure may rally metals into the elutriate that would otherwise remain inert.

Chlorinated hydrocarbons - PCBs and pesticides

It is generally agreed that substantial release of these compounds from dredged material does not occur during disposal operations. It might appear, therefore, that seawater elutriation of these compounds should be adequate. Nevertheless, since it is difficult to monitor the longer term release of these contaminants from disposed material, it is recommended that these samples be subjected to total extraction.

Samples should be removed from the box corer with a stainless steel tube (3.5 cm i.d.). Analysis will be primarily for Arochlor 1254 (PCB) (although there is a trend toward congeners or total), p,p'-DDE, dieldrin, and chlordane. Other compounds may be added if, historically, they have been contaminants in the material disposed at the site.

Oil and grease

The term "oil and grease" refers to the organic fraction in natural waters and sediments that is preferentially soluble in organic solvents. The extract contains many fractions that are neither oil nor grease; hence, some investigators prefer to label the material derived by the oil and grease extraction "total extractable matter." The oil and grease fraction in sediments may include fats, oils and waxes of vegetable or animal origin, hydrocarbons of natural origin, petroleum derivatives, organic chemicals, pesticides, detergents, soaps, and elemental sulfur. The plant and animal materials are not toxic and are generally subject to biodegradation; hence, their only impact, if any, may be BOD. These oils may produce floating sheens (as will petroleum oils) that can coat the epithelial surfaces of fish gills or may asphyxiate benthic animals when the floating globs encounter surface debris that eventually sinks to the bottom. Petroleum residues on the other hand may have long-lasting sublethal effects. When oil pollutants are incorporated in sediments below the aerobic layer, they can remain unchanged and toxic for long periods of time until bacterial degradation is complete. In some instances this could alter the composition of the benthic community by killing off sensitive species.

Generally, if one carries out the following two analyses, oil and grease determination is not done.

High molecular weight petroleum hydrocarbons

The quantity of crude petroleum hydrocarbons entering the ocean today amounts to several million tons per year. Crude oils are a complex mixture of hydrocarbons ranging in molecular weight from that of methane to as much as 100,000. Crudes consist of three fractions--oils, resins, and asphaltenes. Of these, the present environmental concern centers on the oils, which are themselves constituted of alkanes, cycloalkanes, and aromatics. The aromatics have been included in the survey plan because of their demonstrated toxicity for both plants and animals. Whether from natural seeps, oil spills, or disposal operations, some high molecular weight hydrocarbons become incorporated into sediment where their residence time increases and their effects on the benthic biota are maximized.

The sediment samples for assessment of high molecular weight hydrocarbons should be removed from the box corer by a glass, stainless steel, teflon, or solvent-rinsed polyethylene coring tube.

Total organic carbon

The sediments of rivers, estuaries, and upper bays commonly contain high levels (4 percent organic carbon or more) of organic carbon washed down from terrestrial sources or salt marshes and seagrass beds. Since these are among the principal sites of navigable channels that must be dredged from time to time, it is not surprising that dredged material frequently contains substantial organic carbon loads. Characteristically, the percentage of organic carbon in sediments tends to drop at the mouths of bays and on the inner shelf. Hence, it is to be expected that if the organic carbon load of sediment dumped in ocean disposal sites is significantly higher than that in the sediment of the receiving environment, the material might have a substantial BOD and might at the same time encourage the development of some benthic organisms. The increase in benthic production caused by the input of dredged material rich in nutrients can be an important monitoring signal, as is discussed in Part IX. Also, TOC could serve as a tracer to check gross movements of dredged material after it has been dumped.

An inimical factor associated with high TOC values, particularly if municipal wastes are a contributing factor, is that they often contain elevated concentrations of ammonia.

Samples for TOC analysis should be removed from the box corer by means of glass or other suitable tubes.

Benthic Fauna

Macroepifauna

The macroepifauna consists of those organisms, such as shrimps, lobsters, crabs, and demersal fishes, that live and/or feed primarily on the surface of the sediments. Demersal fishes are those that swim in the water column but feed upon bottom-living organisms. Benthopelagic fishes live along the bottom but feed at least in part from the water column well above the bottom. Hence, they may not carry the same loads of contaminants as truly benthic species. Nevertheless, they are commonly collected in bottom trawls along with the benthics. It is obvious that many finfish and shellfish of commercial value belong to this ecological category--the macroepifauna. It is difficult to sample most species of the

epifauna quantitatively. Quantitative sampling is difficult with an otter trawl because of uncertainty in calculating the area swept by the net.

It is suggested that the macroepifauna be sampled by means of a beam trawl having a 3-m gape. The advantage of this device over the otter trawl is its fixed aperture, which is held rigid by means of a steel bar (the beam). The beam trawl should be towed along the long axis (or diameter) of the site at a speed of 2 knots for a bottom time of 10 min or so for each tow. One or two tows are recommended at each station. Theoretically, it would then traverse about 615 m per tow while sampling about $1,850 \text{ m}^2$ ($615 \text{ m} \times 3\text{-m gape}$), which should be sufficient to obtain a representative sample of the epifaunal species at most sites. This procedure should be repeated both upstream (perhaps 1 nautical mile away) and at stations located on a line with critical areas or human amenities. It is possible that no clear upcurrent-downcurrent aspects exist in the contiguous area (see discussion of currents that follows). In that event, the macroepifauna should be sampled only at a station or stations toward the shore or toward a special critical area.

The following uses are to be made of the macroepifaunal samples in the baseline cruises:

- a. A simple determination of the gross wet-weight biomass of the macroepifauna has considerable merit, particularly as a part of the monitoring program after baseline values have been established.
- b. Simple species richness should be determined, i.e., the number of species of each type (finfish, shellfish, gastropod, bivalve, etc.) per estimated area covered or time involved (effort) for each haul.
- c. The sorting, as close to species determinations as feasible, may be done aboard the ship, or the entire sample (except as noted below) can be preserved. If needed, representatives of each species can be preserved for precise laboratory identification.
- d. Two species should be selected, preferably a demersal fish (e.g., flounder or other flatfish) and a shellfish (such as a crab, lobster, or large bivalve) and frozen in plastic sacks for metal analyses. Individuals of the same species used for metals should be wrapped individually in treated aluminum foil and frozen for PCB, chlorinated pesticide, and petroleum hydrocarbon analyses. All specimens used for metal analysis or other methods of analysis should be kept and preserved for species verification.
- e. Treatment of beam trawl samples used in monitoring is discussed in Part IX.

Macroinfauna

These organisms are defined by being over 0.5 mm in length and by living in the sediment bed. Among the principal taxonomic groups of the macroinfauna in marine sediments are polychaetous annelid worms and bivalve molluscs. It is possible to quantify the populations of the predominant macroinfaunal species at a given station. But to do so requires that the samples be taken with a good box corer or, possibly, a Smith-McIntyre grab. Sufficient samples must be taken at each station to establish sampling precision. Also, the length of the core should be uniform throughout. As noted above with granulometry, the core need not be more than 10 cm long.

Based on the work of Saila, Pikanowski, and Vaughan (1976) and McIntyre (1971), among others, it is advised that five box cores or grabs per anchor station should account for most of the within-station variance. If for some reason the number of cores per station has to be reduced to, say, three, the number of stations should be increased proportionately to give the same number of samples for analysis.

The five most abundant species will very likely account for at least 85 percent and possibly as much as 95 percent of the biomass of the infaunal species. The following determinations are recommended for the macroinfauna:

- a. Determine species richness, as for macroepifauna.
- b. Determine numerical abundance. As mentioned above, the most abundant groups will likely be led by polychaetes, bivalves, amphipod crustaceans, and occasionally sipunculid worms.
- c. Separate the two most abundant species groups and identify all individuals to species.

The BRAT Technique. The principal physical effect of the disposal of dredged material is a change in the sedimental constitution and gross physiography of the seafloor. There is a possibility that this will decrease the value of the seafloor as a feeding area for commercially and recreationally important bottom-dwelling fishes. The Corps of Engineers developed a set of procedures to evaluate this potentiality (Lunz and Kendall 1982, Clarke and Lunz 1985). It is referred to as BRAT (Benthic Resource Assessment Technique). When combined with REMOTS (Rhoades and Germano 1982), one can document the significance of impacts and predict changes in forage-value of the bottom with increasing time from the disposal event. Again, it is important that the site manager have at least cursory knowledge of the infaunal successional stages that are characteristic of the area. For the most part, these will be polychaetes, bivalves, and amphipod crustaceans.

There is a tendency for demersal fishes to be omnivorous in the sense that at any given time in their life history they will eat prey they can most efficiently detect, capture, and ingest. This explains the differences in the diets of different fish species, of different age groups of the same species, etc. For instance, larger fish tend to forage deeper in the sediment bed than smaller species, and the same is true of different species. Knowing this about a species and armed with knowledge of the invertebrate assemblage present in the sediments down to the critical depth, a site manager can estimate the forage value of a disposal site and its environs. The BRAT clearly requires knowledge of the depth and size distribution of the benthic invertebrate community. This information is gained by analysis of box core samples, carefully separated into vertical subsamples, and by stomach-content analyses of fish caught in the beam trawl (for use of sediment profilers and BRAT in monitoring, see Part IX).

Sampling for BRAT analysis. The information in this section is based upon Fredette et al. (1990).

Information on the benthic assemblages within a given project area is obtained from quantitative benthic samples. A box corer capable of penetrating at least 30 cm into an unconsolidated bottom and having a cross-sectional area of at least 0.06 to 0.07 m is needed. The corer used must be adapted for use with a removable liner that has a removable side. A Gray-O'Hara box corer (see Part VII, Figure 23) has been successfully modified in this

manner and used in sample collection. Care must be taken to ensure that an undisturbed sample is taken. Any sample that does not include at least 30 cm of material or shows signs of being disturbed is discarded. The number of replicate samples taken is determined by the sample design and statistical considerations but may also be affected by constraints in processing time. Typically, at least four to five samples should be taken in any given site (e.g., impacted and reference areas). Location of sampling sites within the project area can be facilitated by the use of reconnaissance techniques (e.g., preliminary grab samples or sediment profiling camera survey).

Upon collection of a sample, the liner is removed from the corer and placed on its side (in a processing box that prevents slumping of the sediment) to facilitate sectioning. The removable side of the liner is removed, and the core is sectioned at 2, 5, 10, and 15 cm from the top of the corer using thin metal blades. The top 0- to 2-cm section is washed through a 0.25-mm-mesh sieve to capture surface-dwelling juvenile stages of benthic organisms. All remaining sections are washed in a 0.5-mm-mesh sieve. All fractions are preserved in 10-percent buffered formalin and stained with Rose Bengal. Organisms from each sample are picked and sorted to major taxonomic categories (e.g., oligochaetes, polychaetes, gastropods, etc.) and temporarily stored in 10-percent formalin. Organisms of each taxonomic category are separated into discrete size classes using a wet sieving procedure modified after Carr and Adams (1973). Samples are carefully washed through a series of nested sieves (6.35, 3.35, 2, 1, and 0.5 mm for each depth section, plus 0.063 mm for the 0- to 2-cm section). Fractions from each sieve are transferred to weighing bottles after filtering through a millipore filter apparatus (filter type HA, 0.45 μ). Weight is determined to the nearest 0.01 mg.

Fish food habitat samples are obtained from collection of demersal bottom-feeding fishes inhabiting disposal and reference areas. An otter trawl is a commonly used means of collecting sufficient numbers of specimens from a wide range of size classes. Fish collection is directed by the number and composition of fishes present in a given area. Optimally, a minimum of 10 individuals of the following size classes of each target species should be collected: 5 to 9.9 cm, 10 to 14.9 cm, 15 to 19.9 cm, 20 to 24.9 cm, 25 to 29.9 cm, and greater than 30 cm. It is recognized, however, that it is not always possible to obtain individuals from all size classes for each species, given the seasonal variability in habitat utilization by different species and different size classes. Each specimen collected is classified, measured, and assigned to a given size class. Stomach contents are then removed, and the pooled stomach contents sample for each species-specific size class is preserved in 10-percent buffered formalin and stained with Rose Bengal. Each sample is picked, sorted, size-sieved, and biomassed in the same manner described for benthic samples.

Data analysis. Application of the BRAT requires the integration of information from the previously described benthic and fish collections from a given project area. Size selection information obtained from fish stomach analyses is plotted for each size class. This procedure is repeated for each predator collected, and the combined matrix of prey size distributions versus predator species/size classes is analyzed using cluster analysis. The output generated from these analyses objectively classifies the fish size classes present into groups based on similarities in prey size distribution patterns. Determination of the available depth zone or maximum feeding depth in the sediments used by a specific

demersal predator is accomplished by comparing prey size distribution patterns in a predator's diet with size-class patterns in the benthic community.

Meiofauna

These organisms are defined as being between 0.5 and 0.062 mm in length and living in the sediments. Thus, the smallest of them are equivalent in size to a 4-phi sediment grain, which lies between fine sand and coarse silt. Accordingly, these organisms have a very intimate dependency upon the condition of the sediment and the constitution of the interstitial water. Although meiofaunal studies are not commonly used in environmental regulatory monitoring programs, they may assist in interpreting data on more commonly studied groups, such as macroinvertebrates. Until a broad data base on meiofauna is developed, conclusions drawn directly from meiofaunal studies should be supported by data from more traditional studies of macroinvertebrates. Inclusion of the meiofauna in the ocean surveys follows the 1977 Regulations and Criteria (Part 228.13(e)(4)). The group can provide a solid monitoring tool. The advantages of working with the meiofauna are:

- a. They can be sampled quickly.
- b. Only two species groups, nematodes and harpacticoid copepods, are sufficiently abundant to be dealt with in sample analysis. Studies should be limited to these two groups.
- c. Fairly reliable quantification can be achieved by technicians after a brief training period.
- d. Sampling of these organisms, requiring two samples per grab, is such that samples for metals, pesticides, PCBs, high molecular weight petroleum hydrocarbons, etc., can be taken from the same grab.
- e. They are predictably responsive to major shifts in grain size, e.g., nematode populations often increase dramatically when sand attains values of 60 percent or more of sediment by weight.
- f. It is possible that some meiofaunal components which are influenced by sediment pollutants are engulfed either directly or indirectly (via one or more species of macroinfauna) by a species used as food by man.

Among the disadvantages are:

- a. The analyses are labor intensive and costly.
- b. There may be high variability.
- c. They may not represent long-term conditions.
- d. Many are pioneer species.

Two meiofaunal samples (well spaced) are taken from the meiofaunal grab or box corer at each station by means of 3.5-cm (i.d.) plastic tubes. Only the top 5 cm of the core is retained for analysis. In practice, all tubes are emplaced together in the sediment of the grab or corer before any major disturbance of the surface occurs. Thus, the following tubes may be involved:

- a. Meiofauna - 2 tubes, plastic.

- b. Granulometry and human debris - 2 tubes, plastic.
- c. Metals - 2 tubes (1 for mercury, 1 for other metals).
- d. PCBs, etc. - 1 tube, stainless steel.
- e. Petroleum hydrocarbons - 1 tube, stainless steel.

This totals eight tubes with a combined area of about 90 cm². With 900 cm² in a 30- by 30-cm box corer, there is enough room to space the samples evenly so they do not interfere with one another.

OTHER MEASUREMENTS

Hydrodynamic Features

The following measurements should, if deemed necessary, be made while the vessel is anchored, both fore and aft when feasible, and very likely at the center of the site. These, if taken, are a "snapshot in time" and may be inadequate to evaluate the effectiveness of certain management options, such as subaqueous disposal or capping.

- a. Wind and swell.
 - (1) Estimate the direction and speed of the wind. One station is sufficient, but observations should be made at least twice during the sampling regime.
 - (2) Estimate the height, speed, and direction of the swell. Note these relationships with wind speed and direction. Throughout the survey, note the relationship between wind, swell, and chop. Also, time the period of the wave, i.e., the time between the arrival of wave crests at the vessel.
 - (3) Estimate from the tide chart the tidal stage at the time the wave observations are made. Also, this information will be vital to an understanding of the current regime. Note differences in water movements, if any, when the tide changes.
 - (4) Look for surface manifestations (e.g., slicks) of internal waves and their period.
- b. Currents and water mass movements.
 - (1) Using a deck-readout current speed and direction meter, determine the nature of the current near the bottom. If the water column is two-layered, as noted by the presence of a discontinuity such as a thermocline or halocline, record the current between the surface and the discontinuity and also near the bottom. If the site is relatively shallow (10 to 20 m), note whether the current meter surges shortly after passage of a wave crest at the ship. The effects of wind chop will not ordinarily be detected at the bottom, even in shallow water, but swell that travels from considerable distances at high speeds will. A rule of thumb states that a swell will disturb the bottom if the depth is not much greater than the wave length. Also, note the color of the water; if it is turbid, check the distribution of the turbidity with vertical hauls of a transmissometer. Attempt to ascertain whether the turbidity is due to some extrinsic source, such as riverflow, or from swell disturbance of the bottom. Current measurements should be made upstream and downstream as well as in the site.
 - (2) Note the movement of the upper meter or so of water by discharging a series of fluorescent dye packets (available at a marine hardware). Time their

movement, and plot their direction of flow against that of wind and swell. One can use the survey vessel to advantage since its length at the water line will be known; hence, the speed of surface flow can be determined by timing the movement of dye from end to end of the vessel.

- (3) It may be necessary to verify mass flow of water by deploying one or more small drogues or expendable current probes. Follow for a sufficient time to establish the circulation past the site. Consider deploying two drogues outside the site (upstream and downstream, if known) and one in the center of the site.
- (4) If it has not been done, profile the water column with an appropriate conductivity-temperature-dissolved oxygen-depth probe to determine the temperature-depth and other characteristics of the water column.

Bioaccumulation and In Situ Bioassays

Bioaccumulation may be defined as the taking up and storage by an organism of a non-food compound until it reaches concentrations above those in the ambient environment, including the storing organism's food (Figure 21). Thus, one is investigating bioaccumulation when conducting analyses of various tissues for trace metals, PCBs, petroleum hydrocarbons, etc., as discussed earlier. Unfortunately, this action leaves some doubt as to

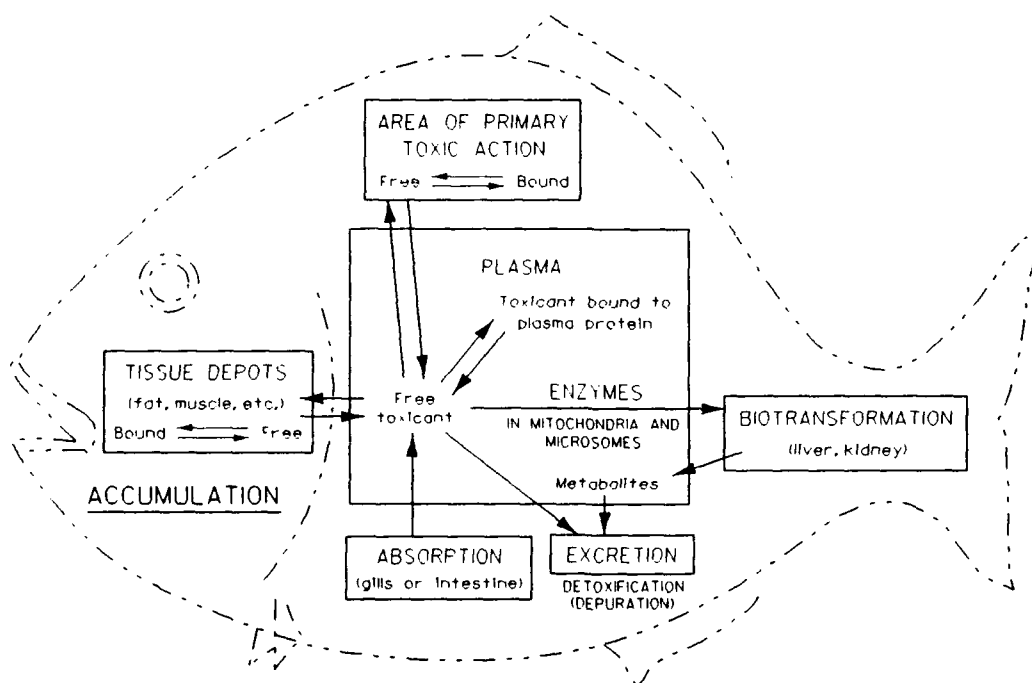


Figure 21. Diagram of bioaccumulation and processes influencing the amount of a toxicant reaching the site of its primary toxic action in aquatic organisms (after Fingl and Woodbury 1965)

where the organism picked up the contaminants, if any; what its normal body burden is; and how long it takes to accumulate a toxicant to above ambient levels. Finally, and perhaps most important, it does not really reveal whether the organism is stressed by this accumulation. Bioaccumulation can be determined by the technique of either laboratory or field bioassays.

Samples for analysis of pollutants in organisms may have to be taken from three loci: (a) in the site, (b) at a reference site, and (c) if there is a flow from a contaminated river or embayment discharge, at a control site (see Figure 22 and caption for further explanation).

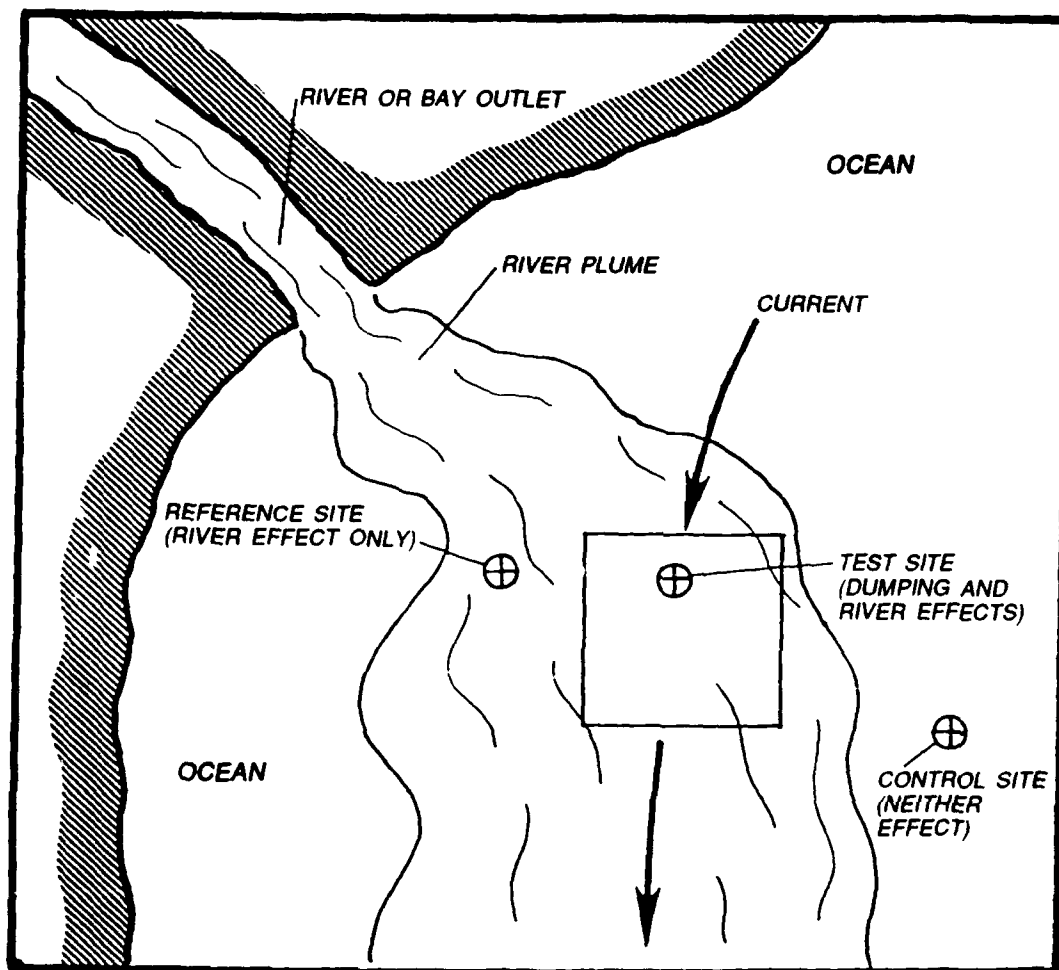


Figure 22. Diagram showing the relationship among reference, test, and control sites when a polluted river flows over a dredged material disposal site. The reference site is the control for the test site, since the tested variable difference is the disposal. The control site per se is the control site for the reference site where the test variable is the polluted riverflow in the ocean

One basic advantage of the use of large species is that one has a large enough sample to utilize muscle tissue for accumulation. This can be significant. There are various places in the body of organisms where contaminants may lodge. Obviously, the liver is such a metabolic pool, but this would be expected because, as is shown in Figure 21, it transforms many contaminants, often into harmless materials that are excreted. Fat-soluble contaminants, such as DDT, may be deposited in fat (adipose) tissue, where they remain until the fat depot is called upon as an energy source. The liver and adipose tissue are relatively unimportant metabolic pools, not only because contaminants are quickly rallied from them, but also because man does not for the most part eat these tissues from crabs or fishes. Much more important is muscle tissue, which man does eat. This is a metabolic pool that is slow to accumulate and slow to give its burden up. Whereas it is difficult to get effective muscle samples from polychaete worms, it is not from other sedentary organisms, such as molluscs.

PART VII: IMPLEMENTATION OF THE SAMPLING PROGRAM

INTRODUCTION

In any ocean survey, certain requirements must be met in order to ensure success. Seven major items stand out as essential: (a) adequate vessel equipped with a modern navigation-positioning system and a precision depth recorder, (b) presurvey plan, (c) experienced cruise leader and aides, (d) complete documentation, (e) correct sampling equipment and proper use, (f) accurate labeling, and (g) proper sample collection and preservation. These cannot be rated in any order of importance since a deficiency in any one of them will probably result in the survey being unsuccessful. Unsuccessful in this context may mean anything from inadequate site coverage, to an unusable sample, to no sample collection. Availability of the above items does not guarantee successful sampling; however, it will greatly increase the probability of success. With the exception of (c), the items listed above are addressed in more detail in this part. (A detailed "Chief Scientist's Guide for At-Sea Operations" is presented as Appendix D.) Approximate survey time and cost requirements are discussed in Appendix E. Appendix F presents a partial list of survey items and manufacturers.

VESSEL REQUIREMENTS

Size and Design

The vessel must be capable of operating effectively at the site. It must be remembered that the depths of the 108 disposal sites under consideration in this study range from less than 2 m to over 2,000 m; 80 percent of the sites are located in waters less than 40 m deep. In practice, vessel selection will be controlled mainly by the depth; thus, the choice will most often be a compromise between the desirable and the feasible. A blue-water oceanographic ship may be required for surveying deeper sites; however, they are generally deep-drafted and cannot operate in very shallow water. The size of the vessel is also dependent upon the anticipated sea state at the site. Generally, it is not possible to sample effectively or safely with a small vessel (less than 80 ft) in seas greater than 4 to 5 ft unless the vessel is specially designed to meet such conditions.

In addition to meeting size requirements, the vessel must be properly equipped to handle the sampling equipment and the samples. For the purposes of this section of the report, it is assumed that the following kinds of equipment may be used: box corer or bottom grab, benthic trawl, water samplers, standard bottom cameras, sediment profiling camera, current meters, side-scan sonar and, possibly, a subbottom profiling system.

Navigational and Positioning Aids

Loran-C

Most commercial and academic research vessels of appropriate sizes for ocean surveys are equipped with Loran-C. If any other system is employed, it should be superior to Loran. Since monitoring requires the taking of repeat samples at the same station after various time intervals, it is obvious that data would be useless without accurate positioning.

Loran-C systems are generally accurate enough for sampling but may be inadequate for some types of bathymetric profiling. The advantages of Loran-C over other available systems are that

- a. The receivers are quite inexpensive, ranging from less than \$800 to \$2,500.
- b. The US Coast Guard operates the Loran-C network, which uses pulsed radio waves at 90 to 110 kHz.
- c. The positioning accuracy is reasonably good over a distance of about 1,300 miles from the master and slave stations.
- d. Its repeatable accuracy generally varies between 50 and 300 ft, although it depends upon many factors. The local Coast Guard can advise as to various types of interference that will affect its accuracy.

Loran-C receivers measure the time difference between the master and coded slave signals; the microsecond difference in arrival time is plotted on special Loran-C latticed charts as lines of position. Since repeatability of sample location is the criterion, the bridge and chief scientist's logs should express positions initially in terms of Loran-C coordinates.

Microwave positioning

Several short-range microwave positioning systems are available for offshore work. The one valuable advantage of microwave systems is that their positioning accuracy is as little as 3 to 10 ft plus or minus a given point. Hence, if the environmental manager has this option over Loran-C, he should avail himself of it. However, the microwave positioning has some overall disadvantages:

- a. Shore stations (transponders) must be positioned very accurately, and when left unattended are vulnerable to vandalism.
- b. The useful range of the system in coastal waters seldom exceeds 25 miles and may be less than half that much. The system is limited to radio line-of-sight.
- c. The master receiver-transmitter is mounted on the survey vessel with the entire system costing anywhere from \$35,000 to over \$100,000.

The shore transponder signals are picked up by the ship, each giving a position circle that varies with transit time from shore to ship. The vessel location is reckoned as the intersection of the two circles.

GPS systems

The GPS systems are satellite navigation systems that are destined to replace both Loran-C and the short-range microwave systems. At this time, most survey and monitoring programs will be served quite adequately by Loran-C and microwave systems.

Echo Sounding Systems

Bathymetry is an essential part of an ocean survey for site characterization and of monitoring during and after completion of the disposal process. Since the majority of sites are nondispersive, it is essential to know where the material was placed and how much of it can be accounted for. Bathymetric surveys require precision depth recording and

microwave positioning accuracy, especially if one is attempting to calculate volume changes over a period of time. After making corrections for the speed of sound in water and other matters, an appropriate 200-kHz, narrow-beam echo sounder should have an accuracy of 1 ft or less.

Benthic Sampling Requirements

Box corer or benthic grab

For the box corer or grab the vessel must be equipped with a davit (boom or A-frame) that will extend outboard for sampler clearance. Normally, the height of the davit should be sufficient so that the gear can be swung in and out manually. This in-out action can also be achieved using a hydraulically controlled davit. In the area where the box corer or grab is to be deployed, it is advisable for safety of operation to have a removable guard rail so that the devices may be kept as close to the deck as possible during launch and retrieval. Always use tag lines.

In addition to a davit, an electric or hydraulic power hoist equipped with a line accumulator is required. In depths less than 40 m, a powered capstan and double-braided nylon line may be the best choice (double-braided lines are preferable to three-stranded lines as they do not twist under strain). The capstan-nylon line combination affords the positive, quick, and controllable response needed for safe operation. Also, the nylon line adds to the shock absorbance capacity of the line accumulator system. For ease of hand-hauling, the minimum line diameter is 0.5 in. (breaking strength of about 7,000 lb). If wire rope is to be used, the winch must have a positive, quick, and controllable response system such as that given by a hydraulic type.

Trawl

If trawling is to be done at the site, the basic shipboard requirements are about the same as for box coring, i.e., a winch and A-frame (davit or boom). If not already secured for towing, the A-frame must be forward-stayed. In addition, the winch need not be the hydraulic type. Under normal towing speeds (~ 2 knots), a scope of 3 or 4 to 1 (wire to depth) will usually suffice in depths to around 100 m; therefore, the winch should be equipped with a minimum of three times the depth plus an additional 100 m. The 100 m will take care of the amount needed to go from the winch through the A-frame and trail back to the water, and the wraps which must remain on the winch drum. Generally, in deeper depths a smaller scope off-wire can be used. Other trawling requirements would be (a) a line accumulator, (b) a metering device for determining amount of wire out, and (c) a powered capstan, which is sometimes needed to bring aboard a heavy sample.

Specialized equipment

In areas where trawling is not possible, other sampling devices such as traps, bottom cameras, and television have been recommended. The use of traps should pose no problems if the vessel is equipped for box coring and trawling since a winch (and/or capstan) and davit are all that are required.

Use of bottom cameras or television may require specialized electronic equipment to determine their height above the bottom. Additionally, specialized winches may be required, especially in deeper water, if a conductive cable is used. It is imperative,

therefore, that the contractor detail any of his special needs to the person in charge of vessel procurement and outfitting.

The sediment profiling camera (SPC) is a photographic system that is not yet in general use but can yield a great deal of both physicochemical and biological data about the benthic environment when properly used. The camera design allows undisturbed profile images of the top 15 to 20 cm of sediment to be obtained rapidly while preserving the organism-sediment relationships. It is important to note that because of its unique design the camera is not affected by turbidity (Revelas, Germano, and Rhoads 1987). It is also important to understand just what the SPC can and cannot do. To derive the greatest advantages of the system, one must have a sound conception of the dynamics of infaunal community structure in the area under study (Germano and Rhoads 1984). In essence, this allows one to deduce community dynamics from structure (Rhoads and Germano 1986).

The camera provides a vertical view of the sediment-water interface as the frame in which it is mounted is lowered to the seafloor. The system includes a computer image analysis for rapid interpretation of a wide range of variables. Typically, about 30 SPC stations can be mounted in a day yielding 100 images. The stations are generally spaced anywhere from 100 to 400 m apart. In addition to measuring depth of surface sediment layers to a maximum depth of 18 to 20 cm, the photographic image reveals surface roughness and grain size. Fredette et al. (1990) advise that the primary advantage of the SPC is its use as a reconnaissance tool. By mapping large areas in a day, such as a dredged material mound, it is possible to place benthic sampling stations effectively. It is reported that one can actually reduce the number of grab samples required for effective statistical analyses.

Rhoads and Germano (1982) point out that although the profiler is not a totally effective source of quantitative data, it will reveal grain size, surface relief, the actual sediment level of the redox potential discontinuity, epifauna present in image area, organism tube density and types, thickness of fecal pellet layer, microbial aggregations, infauna present in the image area, and successional stage. It is the last two items that, in particular, provide insight into community dynamics from static photos. If one knows the successional stages in disturbed surfaces of a given ecogeographic area, then the profiler can reveal whether the infauna imaged are the first, second, or third stage. Moreover, the size of organisms and the depth of their vertical penetration into the sediments will increase with time. This penetration will bring with it a greater circulation of oxygenated water; hence, the positive redox can be found deeper in the sediment bed with later successional stages. Penetration of the profiler is reduced or impossible in sand.

It is not feasible to expect the profiler to yield useful taxonomic data or quantitative estimates of infaunal diversity, abundance, and biomass. But the data that it does provide can be processed far faster than those produced by more conventional sampling. Thus, it would appear that a judicious use of the SPC and, say, grab sampling could provide more data in a shorter time and for less money than was true in the past.

Water Sampling Requirements

Sampling of the water column will be accomplished by (a) taking discrete samples for onboard or laboratory analysis and (b) measuring the parameters in situ. Discrete samples can be taken using a hand-held line in shallow water or by using a winch and davit in

deeper water. The same winch-davit combination used for box coring can be used for water sampling provided that the line is not too large for messengers or sample bottle attachment. Depending on their weight, in situ devices, such as the STD, transmissometer, and other types of probes, can be hand-lowered in shallow water; however, heavy probes or deeper water require the use of a special winch that can accommodate conductive cable.

Laboratory and Storage Space Requirements

The survey plan should include vessel specifications for laboratory and storage space. For example, if the survey vessel returns to port each night, the needs for laboratory and storage space may be minimal; however, if the vessel is to be away from port for a number of survey days, then laboratory and storage space may become quite significant. Even on day cruises there should be at a minimum a desk for the chief scientist and laboratory bench space of 20 to 30 sq ft for sample preparation and shipboard analyses.

There also must be provisions for refrigeration and freezing. Some samples must be refrigerated, while others require initial quick freezing. Samples requiring refrigeration can be placed and stored in a conventional refrigerator, or they can be placed on wet ice and later stored in a refrigerator. For quick freezing, a forced air freezer, dry ice, or liquid nitrogen can be used; once the samples are frozen, they can be stored in a conventional freezer. The amount of refrigerator and freezer space is dependent upon the number of samples to be stored before land facilities can be utilized.

PRESURVEY PLAN

Essentially, a presurvey plan is a detailed account of what is to be accomplished and how and where it is to be done. The main purposes of the plan are to ensure that (a) samples are taken from the proper location; (b) the chief scientist knows the full extent of the survey; (c) there are expert and trained backup personnel for each operation; (d) all necessary equipment, supplies, and backup are available; (e) all samples arrive at designated laboratories in the proper state of preservation in a timely manner; and (f) all data are tracked and processed.

The plan must contain locations for all primary sampling stations along with a detailed account of the sampling to be accomplished at each station. The plan should explain the intent of the survey so that if the need arises the chief scientist may alter the sampling procedures. It is advisable that an alternate sample station be assigned for each primary station. For example, depth at a primary station may be 1.25 m instead of the 3.5 m as shown on bathymetric charts, and thus the station is too shallow to be sampled. There are many other reasons why it may not be possible to effectively sample a primary site; thus, the plan should indicate an alternate area or at least in which direction an alternate site should be located in relation to the primary site.

It is essential that there be expert and qualified backup personnel for each operation. The plan should list the cruise and onshore personnel along with their primary and secondary responsibilities. The completion of this task should eliminate any unfilled responsibilities as well as ensure that necessary equipment and supplies are available when needed.

The plan shall also contain all logistical operations. This shall include transportation to and from the vessel for personnel, equipment, and supplies; scheduled port calls; sample storage; and sample routine for the respective laboratories.

DOCUMENTATION

Documentation for the survey should include the following: bridge log, meteorology log, chief scientist's log, records and notes by aides, results of shipboard analyses, sample inventory logs, and summary cruise report. Time should be kept on the basis of a 24-hr clock and in local time. Any changes in time zones should also be clearly noted on each log.

The bridge log is maintained by the ship's officer or aide. All events pertaining to the ship and sampling operation should be identified by date, time, position (using navigational aid coordinates and calculated latitude and longitude), instrument used to determine position, and an estimation of position accuracy. It may be advantageous to have the bridge watch keep the meteorological log. The meteorological log should be kept on a printed form having the following minimum entries: date, time, location, weather condition, wind (speed and direction), air temperature, and sea state (height and direction). Meteorological observations should be taken at 3-hr intervals or less. Sudden changes, if they occur within the predetermined observation interval, should also be recorded.

The chief scientist's log shall include as a minimum the time of departure from and return to dock, and the time, depth, location, and type of gear for each sample collected (time, depth, and location at beginning and end of sampling if not on anchor). Any deviations from normal procedures should be noted.

Other records to be kept by the scientific party should include results of shipboard analyses and notes on samples and sample collection. Considering the high cost of operating ships for site surveys, an effort should be made to gather observational data so long as it does not extend the time required for the basic survey. Therefore, special attention should be given to recording sightings of birds, mammals, and turtles during the survey. These components of the fauna, with some being designated as threatened or endangered, are of considerable political as well as environmental importance. Such site-specific data should be used in the description of the environment in an ensuing EIS or monitoring report. Information to be recorded shall include identification or description, number, time, date, location, and estimated direction of travel. If the chief scientist's log is open to all personnel, many of the individual notes can be recorded into it. The above additional observations will enhance the value of environmental assessments to diverse users at little or no additional cost.

It is preferable that the sample inventory log be maintained throughout the survey; however, it can be prepared during demobilization. If more than one site is visited, it is suggested that the inventory be completed by the end of each site survey. The sample inventory log should be in form format and shall identify all samples for laboratory analysis. Information to be reported for each sample shall include, as a minimum, label code number, location (or station number), analysis to be performed, depth, date of collection, and special remarks pertinent to analysis or interpretation of results.

The summary cruise report shall include a list of participants, a map of the station locations, a list of cruise objectives versus data obtained, and a combination and

interpretation on a chronological basis of all logs and notes taken during the survey. Data forms need not be included in the text. However, they, along with originals of all logs, etc., should be appended to the report. As soon as possible, copies of all cruise information should be made and stored in separate locations.

SAMPLING EQUIPMENT AND ITS USE

Box Corer

It is suggested that, where possible, sediment samples be collected with a box corer of the type shown in Figure 23, unless penetration is reduced by substrates. If other devices

are used, they should fulfill the following requirements: (a) obtain a quantitative sample, (b) obtain a relatively undisturbed sample, (c) provide sufficient volumes of sediment for required analyses, and (d) be as noncontaminating as possible.

Ideally, the box corer should be used with the ship on anchor. In deeper water, or when it is impractical to anchor, the following methods can be used to return to the station for replicate sampling: (a) return to the original navigational aid coordinate (this is facilitated if an automatic track plotter is available) or (b) anchor one or more marker buoys and return to the original position relative to the marker buoys.

The lowering technique used for sample collection depends upon the amount of weight attached to the corer and the hardness of the sediment. Weights can be added to the box corer shown in Figure 23. It is imperative to collect an undisturbed sediment sample. When retrieved, the box corer should have at least 1 or 2 in. of water overlying the collected sediment. If penetration is too deep, the sediment will be extruded out the top of the corer (remove weight or drop slowly), whereas too shallow a penetration will not collect enough sediment to form a water-tight seal (add weight). When the bottom is reached and the line is

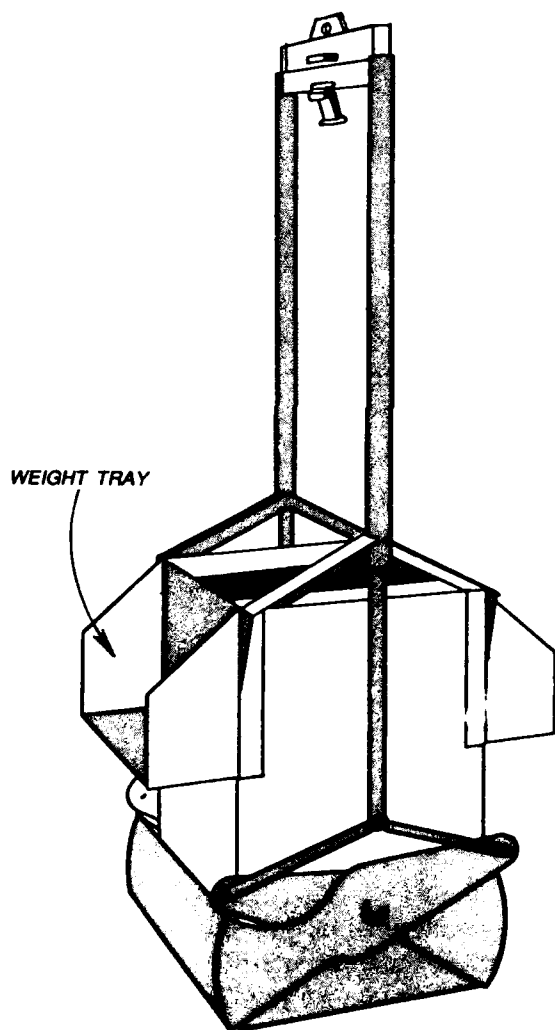


Figure 23. Box corer (Gray-O'Hara modification of the J & O box corer). For deeper penetration in hard sediments, weights can be attached to the shelves located on opposite sides

slacked, hauling in should begin immediately. Any delay on the bottom may increase the wire angle, causing the corer to be pulled out obliquely. It is important to haul in line very slowly until the corer has left the bottom because (a) the closing of the corer is completed as hauling begins, and a sudden jerk may raise the corer before closing, and (b) the corer may be deep in the sediment, and a sudden jerk may damage the corer or break the line. Upon retrieval, the corer should be placed in a suitable container, i.e., a short wooden box with handles and a nonskid bottom. After the subsampling tubes for granulometry and meiofauna (if desired) are in place, the box corer should be tilted slightly and the water above the sediment gently siphoned off. This is necessary if meiofauna are being sampled because some species live in the surficial flocculent layer. Subsampling for the remaining parameters should be done after the overlying water has been removed. For macroinfaunal sampling, the overlying water should be siphoned off before the box corer is emptied into the box.

In the event that a successful sample is not obtained in three attempts and weights have been added or taken off as necessary, an alternative sampling device may be substituted or a secondary station may be visited. The chief scientist's log should document the reasons for the sampling failures and the selection of alternative sampling devices or for visiting a secondary station.

Beam Trawl

If quantitative data are needed, a beam trawl (Figure 24) is the suggested gear for sampling macroepifauna. The beam trawl is often preferred over the otter trawl because the mouth of the beam trawl net is held at a constant opening. The mouth of the net is held open by a steel beam 3 m long with steel runners on each end. A standard net is made of 1.5-in. stretch mesh, and beginning at the throat it has an inner liner of 0.5-in. stretch mesh. The trawl is attached to the towing wire by a short (compared with the otter trawl) three-point bridle. Beam trawls are, however, more susceptible to damage and more difficult to handle than otter trawls.

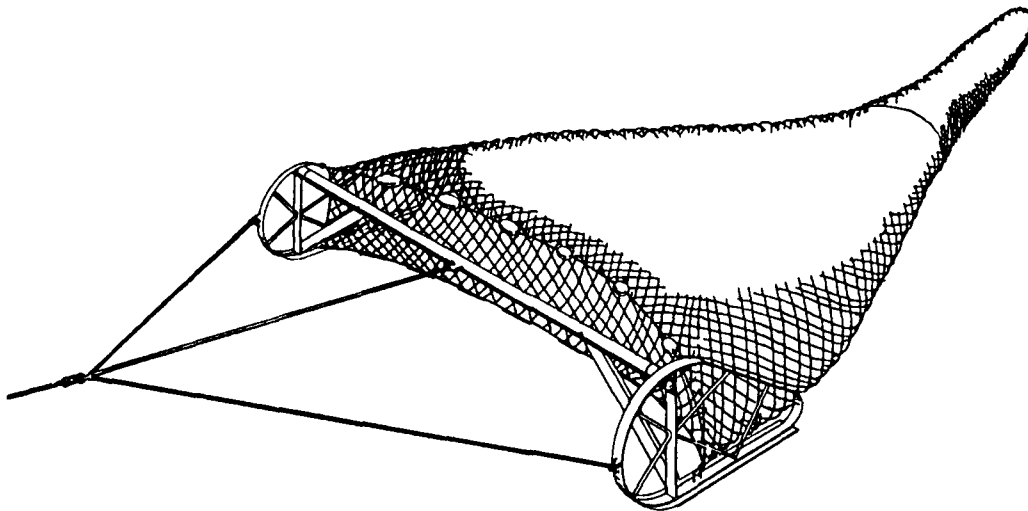


Figure 24. Beam trawl. The beam holds the skids and thus the mouth of the net at a constant opening. Extra strength can be provided using an angle iron brace from the beam to the bottom of the skids

The launching of the trawl may be from the stern or side of the ship. If the towing is to be from the side of the ship, the wind must be blowing onto that side during launch and retrieval, so that the ship is blown away from the net to avoid entanglement with the ship's propeller or rudder. If the net is to be launched from the port side, for example, it is sometimes advantageous to have the ship in a shallow port turn. When stern launching the trawl, one should be sure that the net is shot far enough aft to be out of the backwash of the propellers. It may be necessary to momentarily stop the engines (but not the forward motion) until the net is clear of the stern. After the net is clear from either stern or side launching, and the trawl is upright and untangled, the wire should be paid out under slight tension. In depths to about 30 m the amount of wire needed will be about three or four times the depth plus the amount of wire needed from the metering device to the water. Past a depth of 30 m, the wire required may be lessened to about 2.5 times the water depth. When sufficient wire has been paid out, the ship's speed should be adjusted to around 2 knots. A suggested standard towing time is 10 min on bottom or, if appropriate, over a fixed course. In any case, a uniform tow speed and time should be adhered to for a particular area. The ship's position should be recorded for the beginning and end of the 10-min period. After the net is brought aboard, its contents should be emptied into a non-contaminating container and photographed. A thorough examination of the net is required to make sure all organisms have been removed so that they will not contaminate the next sample. Finally, the net should be thoroughly washed with site water.

Salinity-Temperature-Depth/Dissolved Oxygen Probe

For determination of these standard oceanographic water column parameters, a salinity-temperature-depth/dissolved oxygen (STD/DO) probe system is recommended. Although these probes are generally not as accurate as the reversing thermometer-Niskin bottle method, they are sufficient for the descriptive work recommended herein. The calibrated minimum accuracy of the system should be: temperature $\pm 0.1^{\circ}\text{C}$, salinity ± 0.1 ppt, depth ± 1 percent full scale, and dissolved oxygen ± 0.1 ppm. The instrument should be calibrated according to the manufacturer's instructions and verified in the field. Verification shall be performed on a water sample collected at a depth of 1 m simultaneously with STD/DO probe measurement. Temperature verification shall be made using a National Bureau of Standards certified thermometer or better. Salinity should be verified with an instrument having an accuracy of at least ± 0.01 ppt. If a dissolved oxygen probe for in situ measurements is not available, the DO shall be analyzed by a method equivalent to or better than Strickland and Parsons (1972).

If a STD/DO probe system is not available or if near bottom cannot be reached with it, these parameters must be collected using the standard oceanographic technique of reversing thermometers and water bottles and then analyzed as outlined above for verification samples.

Turbidimetry/Nephelometry

In some instances it may be desirable to obtain reasonably quantitative measurements of the turbidity of waters caused either by the dredging or disposal process. In simple terms, the cloudiness in a liquid caused by the presence of finely divided, suspended material is termed turbidity. This quality of the water column can be measured either by a nephelometer or a turbidimeter, the latter often being called a transmissometer. There is

some overlap in the usual conception of these two instruments. Both have a light source and a detector, which are separated by a static or flowing sample of the turbid liquid. In nephelometry the intensity of the light scattered at right angles to the light beam by the suspension is measured, whereas in turbidimetry or transmissometry the decrease in the intensity of directly transmitted light is recorded. The advantage of nephelometry is its greater sensitivity, accuracy and precision in the determination of small amounts of turbidity.

Turbidimetry is somewhat simpler and better for more highly turbid solutions even though the calibration curves deviate further from linearity than those of nephelometry. Most instruments employed in routine oceanographic surveys are essentially turbidimeters. By using a known volume of solution in comparison with a standard, the instrument can determine the mass effect resulting from the number and size of particles in the solution. Since most dredging/disposal turbidity is caused by clay-size particles whose size can be estimated, it is possible to derive the particle concentration.

Ordinarily the turbidimeter is either towed horizontally or hauled vertically. Thus, when it is coupled with a deck readout and in some cases with a recorder and computer, the operator can trace the movement and extent of the turbidity cloud.

Water Samplers

Water samples for trace metals, hydrocarbons, and pesticides are to be collected very near the bottom at all sites and in middepths at some of the sites. Samples may be collected using water sampling bottles or a submersible pump system. Whatever sampling device is used, it must be noncontaminating to the kind of sample collected.

The preferred method for sampling very near the bottom is a sample bottle equipped with a bottom-activated closing mechanism. To be noncontaminating the bottle should be nonmetallic (if used for trace metal sampling), Teflon lined, and of the close-open-close type. In addition, all components within about 5 m of the bottle (i.e., lowering wire, bottom-activated closing mechanism) should be noncontaminating. (The lowering wire and bottom-activated closing mechanism can be polyethylene sheathed; small components can be coated with epoxy.) The system must be precleaned before each lowering using a 1:1 hydrochloric acid-distilled water rinse for trace metal sampling and a hexane rinse for hydrocarbon or pesticide sampling. To facilitate sampling in deep water, it is advisable to attach a pinger above the sample bottle and at a known distance above the closing mechanism. This enables precise location of the closing mechanism relative to the bottom during any point in the lowering process. The use of a pinger enables samples to be taken under conditions when they otherwise could not be obtained.

For shallow depths a submersible pump system may be preferable. Since the system may become contaminated while being lowered to the sampling depth, sampling should not commence until at least a volume equal to 10 times the tubing volume has been pumped through the system.

Whatever sampling system is used, care must be taken that it will not contaminate the sample. For trace metals (except Hg, where Teflon or glass is required), the bottle should be nonmetallic, and all components of the sampling system within 5 m of the bottle should be nonmetallic. For hydrocarbons and pesticides, the bottle should be glass and precleaned with hexane.

Current Meter

It is desirable that the ship be anchored during all measurements using standard current meters. In shallow water, the ship should be anchored fore and aft, since the ship itself on a single point anchorage could produce up to a 0.2-knot distortion. For near-bottom current measurements in deep water, special equipment may be necessary. A system used by Pequegnat (1972) proved successful in depths over 3,000 m.

The current meter should be one that is least affected by up-and-down motions of the ship and has a recording deck readout component. The deck readout component is preferable since one can readily ascertain if the unit is functioning and if or when the ship's action is influencing the meter. To minimize the up-and-down effect on the current meter due to the motion of the ship when anchored fore and aft, the current meter should be deployed from midship.

One must be cognizant of the fact that the directional component of the current meter is magnetically determined and thereby can be influenced by adjacent metal objects, i.e., ship's steel hull or engine (vessels with wooden or aluminum hulls will produce negligible effects). Additionally, in the vicinity of the ship's hull the current field is distorted; thus, current measurements taken above the draft of the ship are unreliable.

Meteorological observations (wind speed and direction and sea and swell height and direction) shall be taken at the beginning and at the end of the current meter measurements. Additional meteorological observations shall be taken if duration of current meter measurement is greater than 1 hr or if sudden meteorological changes occur during the current measurement.

A Doppler current meter is particularly appropriate for depths over 300 m. However, cost is a major consideration, as these instruments cost approximately \$75,000.

Placement of current meter, duration of measurement, and field use of data are outlined in the "Chief Scientist's Guide for At-Sea Operations" (Appendix D). Essentially, however, current measurements are to be taken very near the bottom and at middepths in order to determine the exact placement of sampling stations (upcurrent and downcurrent) and to determine the current when a two-layered system is present.

Expendable Current Meter

Data that will be very helpful in selecting the location of a dredged material disposal site can be acquired through use of seabed drifters. These devices can be carried along the bottom by relatively weak currents until they are either lost or are retrieved by fishermen or divers. A reward will enhance returns. In some cases, of course, they may wash ashore where people visiting the beach retrieve them from the surf. The drifters carry a water-tight business reply card so that the retriever can mark the location at which the unit was found and then drop it into the mail (Figure 25). The drifters are deployed in bundles of 25 and dropped to the bottom by means of an expendable weight attached to the bundle by means of a salt ring. When the ring dissolves, the units are freed to move with the current. It is possible to derive some conception of the circulation in the area when the units are dropped at different locations and at different points in the tidal cycle and the points of retrieval are carefully recorded.

The value of seabed drifter data can be enhanced by combining the study with current meter measurements through a tidal cycle at several locations. The location both of the current meters and points of release of the drifters should be determined as precisely as possible--preferably by microwave. Tracking of the drifters by means of attaching 100-kHz tags can be accomplished through use of 100-kHz side-scan sonars. One must be aware that the degree of correlation between the movement of drifters and potential movement of sediment from a disposal site needs to be estimated by knowledgeable personnel (Clausner, Birkemeier, and Clark 1986). Disposable current meters can also be used.

LABELING

Correct sample labeling is one of the more important aspects of any field sampling program. There are many label systems, and it would be presumptuous to recommend which is best. Any labeling method, however, should fulfill the following minimum requirements: labeling must be permanent; also, labels should be inside and outside the container, noncontaminating to the sample, readable from the outside of the container, easily traceable to the chief scientist's log, and recognizable as to location of collection, type of sample, and type of analysis to be performed. It is advisable that the label be a simple code or contain a simple code that is easily traceable to the chief scientist's log so it can be used by laboratories in their analysis report. In addition, if there is anything out of the ordinary that may affect the laboratory analysis or its interpretation, the sample label should be flagged to draw special attention from laboratory personnel. An explanation of the flag must be contained in the chief scientist's log and be sent to the laboratory along with the sample. Under some circumstances "chain-of-custody" procedures may be required.

Permanence of the label is a problem. Many permanent inks are not permanent if used in alcohols or other preservatives. Even some India inks will wash off unless they are completely cured on an absorbent type paper. A number two pencil is best for paper labels. If paper is used, it must be 100 percent rag, or there is a good possibility it will disintegrate when wet. If labeling is to be done on plastic, the plastic must be dry and at room temperature and marked with a permanent felt pen. After the ink has dried, the label should be covered and sealed with a clear vinyl waterproof packaging tape that is secured by being placed around the entire container. It must be stressed that whatever type of labeling supplies are used, they must be thoroughly tested for permanence in every type

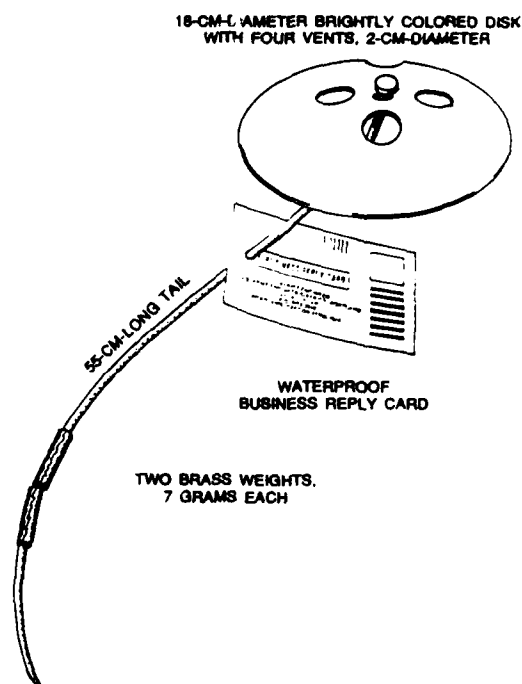


Figure 25. Seabed drifter for measuring bottom circulation (after Clausner and Engler 1988)

of environment to which they may be subjected. Do not assume that just because it tested waterproof that it will be freezer and thaw proof.

Samples for different kinds of analyses may require different labeling techniques, so it is important to plan the labeling technique for each type of sample. The label must not touch a sample on which chemical analyses are to be performed. In this case, the label can be attached to the outside of the container or both container and label can be placed together in a plastic bag. Since the precruise plan will identify the type, number, and general location of samples to be collected, it is advisable to enclose or attach a partially completed label with each sample container prior to the cruise. These can be preprinted.

SAMPLING AND PRESERVATION

Water Column

Trace metals

Two samples are to be collected for trace metal analysis: one for mercury and one for the other trace metals to be analyzed. Sample containers for mercury samples are 1-L glass bottles with caps lined with Teflon. The other trace metal sample containers are 1-L linear polyethylene bottles and caps. All containers, lids, and apparatus (except for filters) that contact the sample are precleaned by the following procedure: (a) thoroughly wash with detergent and tap water; (b) rinse with 1:1 nitric acid, tap water, 1:1 hydrochloric acid, and tap water; and (c) rinse several times with deionized distilled water (USEPA 1976). Bottles may be soaked about 1 month in deionized water with 2 ml ultrapure $\text{HN0}_3/\text{L}$. Filters are precleaned in the same manner with the exception that they are not washed with detergent. They should be placed in a precleaned container and frozen with 2 ml ultrapure $\text{HN0}_3/\text{L}$.

The water sample is collected as above and filtered through a 0.4- μ polycarbonate (Nucleopore) filter. The filter is then placed into a precleaned container, and 5 ml of ultrapure (Ultrex) HCl is added. All filtering and direct sample handling is to be carried out in a clean environment. Samples are stored at 4°C until laboratory processing.

High molecular weight hydrocarbons, PCBs, and chlorinated pesticides

Two samples should be collected: one for high molecular weight hydrocarbons, and one for PCBs and chlorinated pesticides. Samples are placed in glass bottles equipped with Teflon-lined caps. All containers, lids, and apparatus that contact the sample shall be thoroughly rinsed with pesticide-grade methylene chloride (precleaning with microcleansing solution and rinsing with acetone is suggested).

The sample should be collected as previously described, and a minimum of 3 L should be placed unfiltered into the precleaned glass bottle, to which has been added 300 ml of pesticide-grade methylene chloride, and acidified to a pH of 2 (HCl). Samples should be stored in the dark at ambient temperature.

Temperature, salinity, and DO

It is recommended that a STD/DO probe be used to profile the water column from the surface to the bottom or to at least 100 m, whichever is the lesser. If the depth of the site

is greater than 100 m or beyond the depth capabilities of the STD/DO probe, a discrete near-bottom sample shall be taken for temperature, salinity, and dissolved oxygen (near-bottom temperature and salinity need not be taken if documentable by recent data). Discrete near-bottom samples shall be collected as described above for high molecular weight hydrocarbons and analyzed as outlined earlier for verification samples. The STD/DO probe shall be calibrated by the manufacturer's instructions or better. Verification samples should be collected and analyzed as described earlier under recommended sampling equipment.

If a STD/DO probe is not used for profiling the water column, water bottles with reversing thermometers should be used according to instructions equal to or better than those given in US Naval Hydrographic Office Publication No. 607 (dated 1968). The distance between sampling bottles shall be such that the thermocline and halocline are adequately depicted; therefore, the data should be analyzed immediately and perhaps redone until the depiction is accurate. Near-bottom samples should be collected as described above.

Turbidity

It is recommended that a transmissometer with depth indicator be used to profile the water column from the surface to within 1 m of the bottom or to a depth of 100 m, whichever is the lesser. Readings should be taken as often as needed to characterize the water column. In addition, a discrete water sample for total suspended solids (TSS) shall be collected in the most turbid portion of the water column as detected during lowering of the transmissometer and verified during retrieval. To ensure that the discrete sample is collected in the most turbid portion of the water column, it is recommended that (a) a water sampling bottle be attached to the transmissometer cable or (b) the transmissometer be attached to the water sampling bottle lowering line. If the depth of the site is greater than 100 m and beyond the depth capabilities for the transmissometer, then an additional discrete sample for TSS shall be collected very near the bottom. The additional near-bottom sample should be collected as described in the section on high molecular weight hydrocarbons.

For TSS, a minimum of 1 L (4 to 10 L may be needed at some ocean sites) shall be drawn from the discrete water sampler. The sample shall be vacuum-filtered (up to 29 in. Hg) through a preweighed, 0.4- μ polycarbonate (Nucleopore) filter. The volume of sample to be filtered shall be 1 L or the amount required to almost clog the filter, whichever is the greater. After determining and recording the sample volume that was filtered, the inside of the filtering apparatus should be rinsed with about 10 ml of distilled water; then the filter should be vacuumed to dryness (additional distilled water rinses shall be performed at the laboratory). The filter shall then be placed in an individually labeled pillbox (plastic container), stored at ambient temperature, and returned to the laboratory.

Sediment

A 30- by 30-cm box corer should provide ample material so that all samples for the analyses can be subsampled from the sediment collected by a single sampling. Subsamples shall be taken while the sediment is still in the box corer. During subsampling, in order to prevent migration of meiofaunal organisms and prevent chemical contamination, it is important that the subsamples be taken in the following order: meiofauna and

granulometry, trace metals, PCBs and chlorinated pesticides, high molecular weight hydrocarbons, oil and grease, and total organic carbon.

It is imperative that the box corer sample chosen for sediment analysis be as undisturbed as possible. Since a minimum of six box corer samples will be taken at each station (one for sediment analysis and five for macroinfauna), the one chosen for sediment analysis should be the first sample that is retrieved in an undisturbed state. Proper use of the box corer is discussed in an earlier section (see Sampling Equipment and Its Use, page 102).

Meiofauna and granulometry

Two granulometry samples and two optional meiofaunal samples shall be taken from the box corer using precleaned, 3.45-cm i.d. Plexiglas coring tubes. The tubes shall be cleaned in the laboratory by soaking them in 1 N HCl. In the field the tubes shall be washed with fresh water and rinsed with 0.1 N HCl after each use. With the water still in the box corer, the tubes should be pushed into the top 10 to 20 cm of the sediment and rubber stoppers (No. 6 or 7) placed in the tops of the coring tubes. The overlying water in the box corer should then be siphoned off. After all other samples have been taken, an additional stopper should be placed in the bottom of each tube, and the tubes slowly drawn from the sediment. The stoppered Plexiglas tube should now contain the sediment sample plus the overlying water. The overlying water should be carefully decanted onto a 63- μ sieve. Material retained by the sieve should be backwashed into the jar in which the meiofauna sample is to be placed.

For the meiofaunal sample the top 5 cm of the sample should then be extruded (15 cm if sediment is sand), using a plunger placed in the bottom of the tube, directly into a sample jar (glass or plastic). The organisms should then be immediately narcotized using an isotonic solution of magnesium chloride (70 g $MgCl_2/L$ is isotonic with 35 ppt seawater). The sample should be covered with the isotonic solution and shaken vigorously for a few seconds. After the sample has set in a cool place out of the sun for about 30 min, the liquid should be decanted through a small 63- μ sieve. The sieve should then be backwashed into the sample jar and the jar filled with a 5-percent buffered formalin solution. The jar should then be shaken to achieve a uniform mixture of the preservative. The samples can be stored at ambient temperature (do not freeze).

For the granulometry, a 10-cm sample should be extruded from the tube into the labeled container (glass or plastic jar or plastic bag) in which the sieved material was placed. The sample shall be stored at ambient temperature.

Trace metals

Two trace metal samples should be taken: one for mercury and one for the remainder of the trace metals. Each sample shall be subsampled from the center region of the box corer so that metal contamination from the box corer itself will be negligible. Each sample shall consist of a minimum of 40 g and shall be taken with an acid-cleaned plastic coring device preferably similar to a piston corer. (An acid-cleaned, 50-cm³ plastic disposal syringe with the end cut off has been used quite successfully. It is preferable, however, to replace the rubber-ended plunger with one made of Teflon.) Each sample should be extruded directly into a separate, precleaned container (see previous section for cleaning instructions) such as a 40-dram plastic vial with cap. The cap should be secured to the vial

with tape; then the sample and label should be placed in a plastic bag. Samples should be frozen and delivered to the laboratory in a frozen state.

PCBs and chlorinated pesticides

For PCB and chlorinated pesticide analyses, one sample shall be obtained by subsampling from the box corer. A minimum of 100 g of sediment, or about a cup, shall be taken with a noncontaminating scoop, spoon, or corer that has been precleaned with a precleaning solution, and rinsed with water, acetone, and pesticide-grade methylene chloride. The sample shall be placed in a precleaned, freezer-type glass jar that has a lid lined with Teflon. (Do not fill the jar over three-fourths full.) The sample shall be labeled on the outside of the jar, frozen, and delivered to the laboratory in a frozen state.

High molecular weight hydrocarbons

The sample for high molecular weight hydrocarbon analysis shall be obtained by subsampling from the box corer. A minimum of 50 g of sediment, but preferably one half of a pint jar, shall be taken with a noncontaminating scoop, spoon, or corer that has been precleaned as for pesticides. The sample shall be placed in a precleaned, freezer-type glass jar that has a lid lined with Teflon. (Do not fill the jar over three-fourths full.) The sample shall be labeled on the outside of the jar, frozen, and delivered to the laboratory in a frozen state.

Oil and grease

The sample for oil and grease analysis shall be obtained by subsampling from the box corer. A minimum of 100 g, but preferably one half of a pint jar, shall be taken with a noncontaminating scoop, spoon, or corer that has been precleaned as for hydrocarbons. The sample shall be placed in a precleaned, freezer-type glass jar that has a lid lined with Teflon. (Do not fill the jar over three-fourths full.) The sample shall be labeled on the outside of the jar, frozen, and delivered to the laboratory in a frozen state.

Total organic carbon

The sample for TOC shall be obtained by subsampling from the box corer. A minimum of 25 g shall be taken with a noncontaminating scoop, spoon, or corer that has been precleaned as above. The sample shall be placed in a precleaned, freezer-type glass jar that has a lid lined with Teflon or aluminum. (Do not fill jar over three-fourths full.) The sample shall be labeled on the outside of the jar, frozen, and delivered to the laboratory in a frozen state.

Benthos - Macroinfauna

Five replicates should be taken with a box corer at each station chosen for macroinfaunal sampling. Additionally, two granulometry subsamples shall be taken from first and second macroinfaunal box cores. When the box corer is retrieved after a successful lowering, it should be placed in a wooden box. After siphoning off the water, the contents of the box corer should be carefully emptied into the wooden box. (Most sediment cores will retain their integrity long enough to take the sample; however, if the sediment is incohesive, the sample must be taken directly out of the box corer.) Using a large scoop or spatula, the top 15 cm of the core should be removed and placed in a sample container; the top 15 cm of a 30- by 30-cm box corer will fit nicely into a 5-gal bucket. The rest

should be disposed overboard. The sample container should be labeled on the outside and inside, then fitted with a lid. Samples shall be processed (sieved and preserved) within 24 hr of collection. If they are not processed immediately, they should be stored in a shaded area. On vessels that return to port each night, it may be advantageous to process the sample onshore.

Macroinfaunal organisms are defined herein as those organisms that are retained on a 0.5-mm sieve. In practice it is suggested that the sample be washed on nested sieves, i.e., 5 mm then 0.5 mm (within limits the mesh size of the larger sieve is not too important). The larger upper sieve will screen out many of the larger fractions; however, more importantly, it protects the integrity of the 0.5-mm sieve. The sample shall be placed on the top sieve and washed with a gentle spray of fresh or salt water. It should be remembered that most macroinfaunal organisms have extremely fragile bodies that damage easily when handled extensively. When a specimen is observed in a sample during sieving, it should be removed immediately with forceps and placed in a labeled container. After the sample is completely washed, it along with a label shall be placed in a glass or plastic jar that has a lid lined with noncorrosive material. The sample shall then be preserved with a volume of 5-percent buffered formalin equal to at least the volume of the sample. For ease of identification a label or code should also be affixed to the outside of the sample container. The sample can now be stored and transferred to the laboratory at ambient temperatures (do not freeze).

Benthos - Macroepifauna

If possible, macroepifaunal samples shall be collected with a beam trawl. In areas where trawling cannot be done, macroepifaunal samples should be collected using traps. Crab, lobster, or fish traps should suffice. When traps are used, it is recommended that local fishermen be consulted on their design and use. Samples collected by either method shall be treated the same.

The following types of analyses shall be performed on the macroepifaunal sample: a simple determination of biomass; identification and enumeration; trace metals; PCBs and chlorinated pesticides; and high molecular weight hydrocarbons. In order to accomplish the above, two samples at each station are recommended.

All organisms that are returned to the laboratory for chemical analysis must be identified to genus or species and enumerated aboard ship or at the laboratory prior to chemical analysis. It is imperative that these data be consolidated with those of the identification-enumeration portion of the sample so that the entire sample can be accounted for.

Biomass

The determination of wet weight biomass shall be done immediately after the sample is taken from the trawl. It is recommended that a pull-type spring scale having a minimum accuracy of 1 percent of full scale be used for the weighing of the organisms. To accommodate small and large samples, it is advisable that at least two balances of different capacity be available, e.g., 2 and 10 kg. The balances shall be calibrated in the laboratory prior to the survey and verified aboard ship before biomass weighings. A single point verification (minimum) shall be performed using a known weight of approximately one half the balance capacity.

The organisms shall be placed in a previously tared, noncontaminating mesh bag (e.g., nylon), allowed to drain for 1 min, and then weighed using the hand-held balance. The balance serial number, verification weighing, and biomass determination shall be entered into the chief scientist's log.

Tissue samples

Trace metals. First choice for selection of organisms for tissue analysis shall be finfish or shellfish which are directly consumable by man; preferably, both a finfish and a shellfish should be selected for analysis. For trace metal analysis, 30-g wet weight **edible tissue** is required. If this weight cannot be obtained by using a single organism, then enough individuals of the same species can be pooled.

Organisms for analysis shall be removed from the trawl sample with nonmetallic forceps or plastic gloves, and each 30-g sample shall be placed in a separate plastic bag. Then the bag and a label shall be placed into another plastic bag. Samples shall be quick frozen and delivered to the laboratory in a frozen state.

PCBs and chlorinated pesticides. First choice for selection of organisms for tissue analysis shall be fish or shellfish which are directly consumable by man; preferably, both a fish and a shellfish should be selected for analysis. For PCBs and chlorinated pesticide analyses, 100-g wet weight edible tissue is required. If this weight cannot be obtained by using a single organism, enough individuals of the same species can be pooled.

Organisms for analysis shall be removed from the trawl sample with hexane-cleaned stainless steel forceps. Each 100-g sample shall be wrapped airtight in hexane-cleaned extra heavy-duty aluminum foil. Samples shall be labeled on the outside, quick frozen, and delivered to the laboratory in a frozen state.

High molecular weight hydrocarbons. The shipboard procedure for these tissue sample analyses is the same as for PCBs and chlorinated pesticides except that a 50-g sample is required instead of a 100-g sample.

Identification and enumeration

The remainder of the trawl sample after removal of organisms for chemical analysis shall be placed in a noncorrosive 1- to 5-gal container and preserved with 5-percent buffered formalin. The volume of preservative shall be equal to or greater than the volume of the organisms. In addition, the thoracic cavity of fish longer than about 10 cm should also be injected with 5-percent buffered formalin. The label for this sample shall note whether it is the entire trawl sample or only a part as a result of samples taken for chemical analyses. After preservation, the sample can be stored and returned to the laboratory at ambient temperature.

PART VIII: PRESENTATION OF LABORATORY AND FIELD DATA

GENERAL

Selection of an appropriate method to use for effectively presenting environmental data depends not only on the nature of the data but also on its use. Most of the information derived from the water column during the ocean survey, such as the distribution of dissolved oxygen, salinity, and temperature, can best be presented graphically on ordinary graph paper. Data points for the above variables plotted against depth and connected by a smooth curve will give an immediate overview of the physical nature of the water column. Ordinarily, no statistical treatment of these data will be required, because they will be used primarily for site characterization. In general, those variables measured in the survey that will be used in impact evaluation or monitoring studies must be presented in a more elaborate manner including statistical evaluation.

As discussed earlier, changes occurring in the water column when dredged material is disposed generally fit into the category of transitory changes; hence, emphasis will be placed upon interpreting and evaluating quantifiable data derived from the bottom environment. It is generally accepted by benthic biologists that the size, shape, and arrangement of the sediments have a controlling influence on the constitution of benthic communities. Moreover, the dredged material may be expected to have some measurable effects on the sediments--not alone in terms of their texture, but also of their chemistry. These changes in turn may then affect some species of the benthic community more than others resulting in measurable change. It follows that alterations of the constitution of the sediment bed and of the structure of benthic communities can reveal the stresses of disposal of dredged material in the site and subsequently in other areas of possible impact.

To assess these effects, one must compare data derived from affected areas to those obtained from samples collected in a reference area that is similar to the affected areas but is presumably unaffected by disposal operations or their aftermath. Ordinarily, one will be dealing with mean values of sampling stations, and it is frequently easy to see differences among these values. But this may not be enough. In some cases, one must test the statistical validity of these differences and establish confidence limits. Moreover, it may be desirable to evaluate the degree of similarity of stations and lump those that are closely related in our data terms. Obviously, one is looking for statistically significant changes which may reflect ecological changes in benthic communities resulting from disposal. One may be overconditioned to the term stress, however, and expect that all changes of benthic community structure are deleterious. But such is not the case. In fact, the richness and density of a benthic community may not necessarily decrease under stress even though the original dominant species may be replaced by others. Thus, the interpretive step beyond the establishment of statistical significance with regard to ecological relevance and acceptability of change must be made by experienced marine ecologists, environmental managers, and appropriate USEPA and CE officials.

DESCRIPTIVE TREATMENT OF WATER COLUMN DATA

Salinity

Salinity is the total amount of solid material in grams contained in 1 kg of seawater when all carbonate has been converted to oxide, the bromine and iodine replaced by

chlorine, and all the organic matter oxidized. In actual practice the above procedures are not followed. Probes that measured in situ electrical conductivity are in common use today. However, a standard laboratory method for chemically determining salinity is used to calibrate the in situ probes. This procedure is based upon the observation that even when the total concentration of salt varies widely, the relative proportions of the major constituents remain constant. Hence, it is possible to determine salinity by measuring only one major constituent, which is ordinarily chlorine. Thus, chlorinity is determined by titrating a seawater sample with silver nitrate using a potassium chromate indicator. Then salinity is calculated according to the relation:

$$S \text{ (ppt)} = 0.030 + 1.8050 \text{ chlorinity (ppt)}$$

In the open ocean surface, salinity may range from 33 to 37 ppt. But near-shore, where most dredged material disposal sites are located, salinities are usually considerably lower than this as a result of river or other land runoff. Ordinarily, salinity increases with depth along a smooth curve, except where surface evaporation is excessive (Figure 26, Curve B), but in the vicinity of rivers there may be a sharp halocline in which salinity increases abruptly below the overriding fresh water (Figure 26, Curve A). Such a situation may affect the dispersion of the finer parts of dredged material after discharge. Also, this situation created a very stable water column in which the passage of oxygen gas into lower layers will be curtailed.

Salinity is best presented as a plot against depth, as shown in Figure 26. Studies done at disposal sites that are affected by substantial riverflow should include sufficient salinity-temperature-depth profiles in and around the site to document the salinity and other differences.

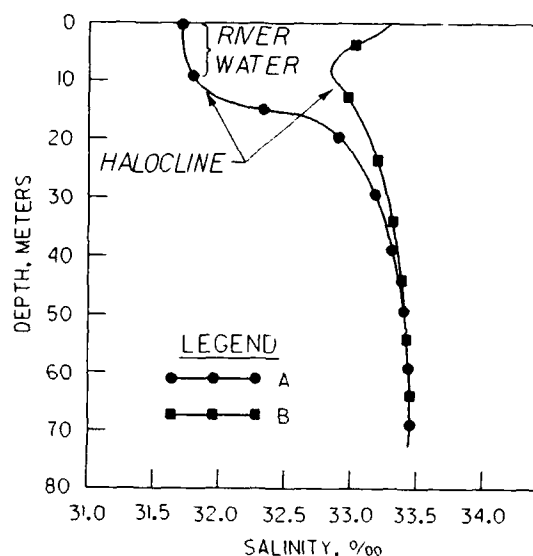


Figure 26. Salinity-depth structure of two imaginary water columns. River water overrides saline water in A, while curve B has a very high salinity water on the surface, possibly as a result of evaporation

Temperature

Temperature and salinity, acting separately and together, are the principal factors determining the specific distributional patterns of marine organisms. Ocean temperatures range from a high of approximately 35° C to a low of -2° C. Most of the water in the ocean is at low temperatures between 2° and 6° C. Unlike the atmosphere, which is heated from the bottom adjacent to earth, the ocean is primarily heated from the surface. Hence, the surface layer stores a great deal of thermal energy from the sun. Since light is quickly scattered and absorbed by seawater, only a thin layer is effectively heated. Thus, as the

temperature probe is slowly lowered into the water, a point will be reached where the temperature begins to drop rapidly. This layer is called the thermocline (Figure 27). There are two types of thermoclines: the seasonal thermocline, which is shallow and a phenomenon of summer heating, and the permanent thermocline (Figure 27), which lies at a depth of about 200 m, well below the depth of most dredged material disposal sites.

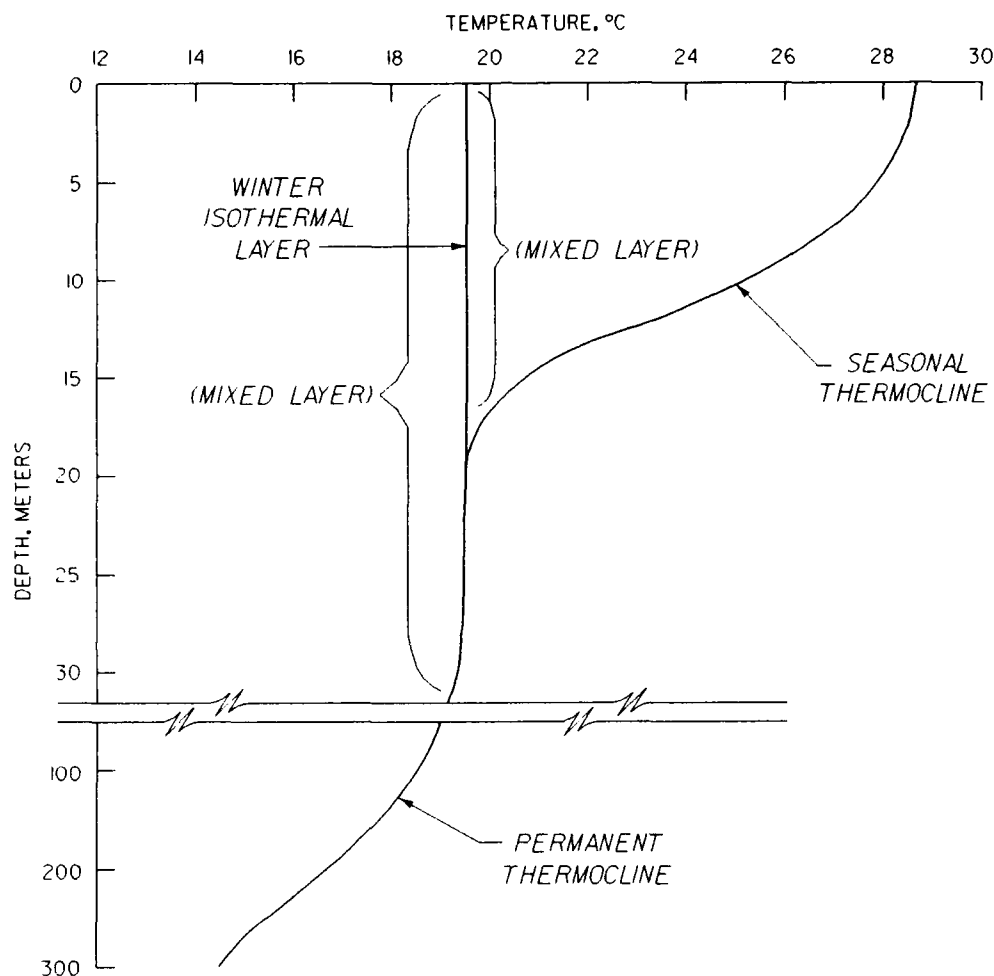


Figure 27. Temperature-depth structure showing the thickness of the mixed layer under control of a seasonal thermocline and its absence. Note position of the permanent thermocline

When a thermocline also marks a rapid change in density with depth (a pycnocline), it may be called a thermopycnocline. It is a real barrier to mixing of waters above and below the cline, and it also can be a layer of accumulation of living and dying plankton, detritus, fine sediment, and other materials. These effects of the thermopycnocline are accentuated where the surface layer has low salinity. In such places one should very carefully measure the dissolved oxygen near the bottom, since there will be very little mixing with surface water where DO enters the system.

The temperature-depth structure should be presented graphically, much as in Figure 27.

Temperature-Salinity Relationships

There are some advantages in diagramming temperature-salinity (T-S) relationships in an area of complicated water mass origin. Ordinarily, however, dredged material disposal sites are too shallow to permit effective use of this technique to identify water masses. Below the surface layer (upper 100 m) there are characteristic relationships between temperature and salinity which remain virtually constant at a single location. This develops from the fact that below the surface there is no significant process by which either salinity or temperature is changed except by mixing. Near the surface, evaporation or rainfall may change salinity, while temperature may be changed by insolation, radiation, etc. Thus, a water mass picks up its original set of characteristics at the surface, but at depth its T-S characteristics can only be changed by mixing with other waters of different characteristics.

After its formation, a water mass spreads at a level determined by its density relative to the vertical density of the water column. The different water masses occurring in a given water column can thus be revealed by a graph showing changes in density. In practice, however, since density is mainly a function of temperature and salinity and the latter parameters are more easily measurable, a plotting of temperature versus salinity (T-S) is used to depict water masses. On a T-S diagram each reversal of the curve denotes a significant change in density and is thus indicative of a distinct water mass. Figure 28 shows two reversals and, thus, the presence of two water masses. The core of a water mass, or in the practical sense that portion that has been mixed or diluted the least, is indicated at the reversal point. The temperature-salinity at the reversal point is a tag that can be used as a tracer for that particular water mass.

Dissolved Oxygen

Dissolved oxygen is a parameter of major concern in several geographic regions where dredged material disposal sites are located. Specifically, reference is made to the New York Bight and a region west of the Mississippi River delta where very low levels of dissolved oxygen have been reported in summer in bottom waters. The atmosphere is the main source of oxygen dissolved in seawater, but rivers are major contributors to nearshore waters. Thus, it is usually near saturation at the surface; indeed, the upper 10 to 15 m may be supersaturated, especially in daylight hours, as a result of the photosynthesis of marine plants (e.g., phytoplankton). Low values of DO in seawater in the open ocean usually mean that the water has been away from the surface for a long

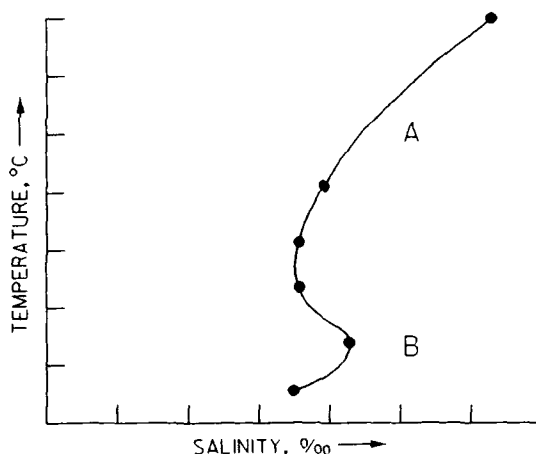


Figure 28. Temperature-salinity diagram from field measurements showing the cores of two different water masses (A and B, which occur at the reversals on the curve)

time. Its original oxygen content has been utilized by animals and in the oxidation of organic detritus. However, locally heavy oxygen demand may be placed on a parcel of water by, say, the rapid dying of phytoplankton organisms at the height of a bloom that was perhaps triggered by some source of eutrophication.

The concentration of dissolved oxygen in seawater is usually reported in milliliters per liter, which represents the volume in milliliters that the oxygen dissolved in a liter of seawater would occupy at standard temperature (20° C) and pressure (760 mm of Hg). The range of values may go from 0 to 9 ml/L, but most fall between 1.5 and 6.5 ml/L.

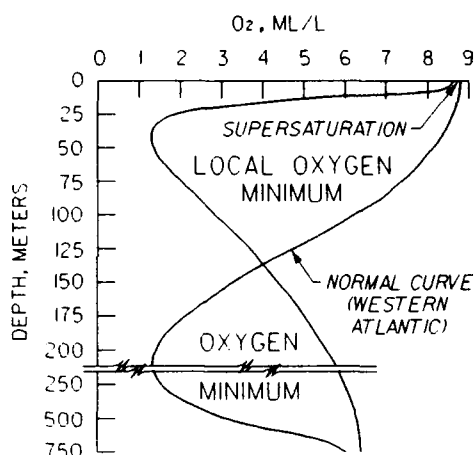


Figure 29. Changes in the concentration of dissolved oxygen with depth. Note particularly the rapid drop toward the

When one plots DO values against depth, one of the characteristic aspects of the curve is its minimum point (oxygen minimum) which occurs above depths of 1,000 m (Figure 29). As noted above, however, minimal values may be reached in very shallow water as a result of local conditions. Dredged material disposal sites on the shelf may from time to time be bathed with water of low oxygen values that upwells from the continental slope. This can also occur as a result of strong offshore winds which push surface water seaward and permit deeper waters to replace it.

Dissolved oxygen values should be plotted against depth, much as in Figure 29. Values of 4 ml/L or above are very satisfactory, but if values in bottom water approach 2 ml/L or lower, additional stations should be added to reveal whether the low oxygen water is local at the site or is coming from the contiguous area.

Other Water Column Parameters

Data obtained from the water column for such parameters as trace metals, chlorinated hydrocarbons, high molecular weight hydrocarbons, and total suspended solids are probably best presented in tabular form. If a sufficient number of samples are available, the data should be subjected to the statistical treatment suggested for the benthic biota in a later section of this part.

ANALYSIS OF SEDIMENT DATA

Information gained during the ocean survey from the benthic environment is important to completion of site characterization and is critical to the establishment of a monitoring effort and to evaluation of impacts of the disposal of dredged material.

The data derived from grain size analysis can be plotted in several useful ways. Various sediments may have different preferred statistical or graphical evaluative procedures, and the literature may help decide which is best for a particular region of the country. However, all of the conventional methods use grain size on the horizontal scale in either phi

units or millimeters and percentage frequency as the vertical scale. If using millimeters, plots should be developed on logarithmic base paper. The preferred method, however, is the phi unit plot, which is done on arithmetic base paper, as shown by the two examples of cumulative curves in Figures 30 and 31.

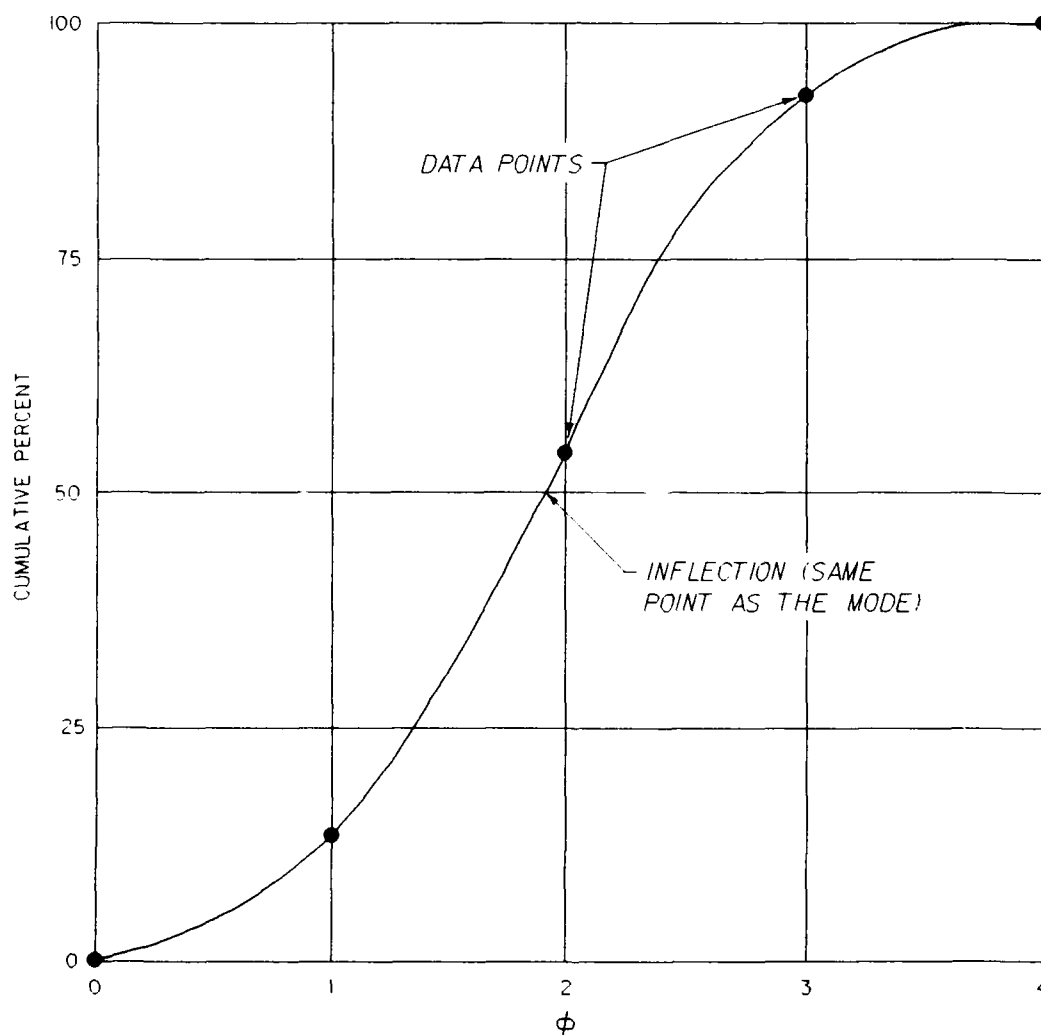


Figure 30. Cumulative curve, arithmetic ordinate

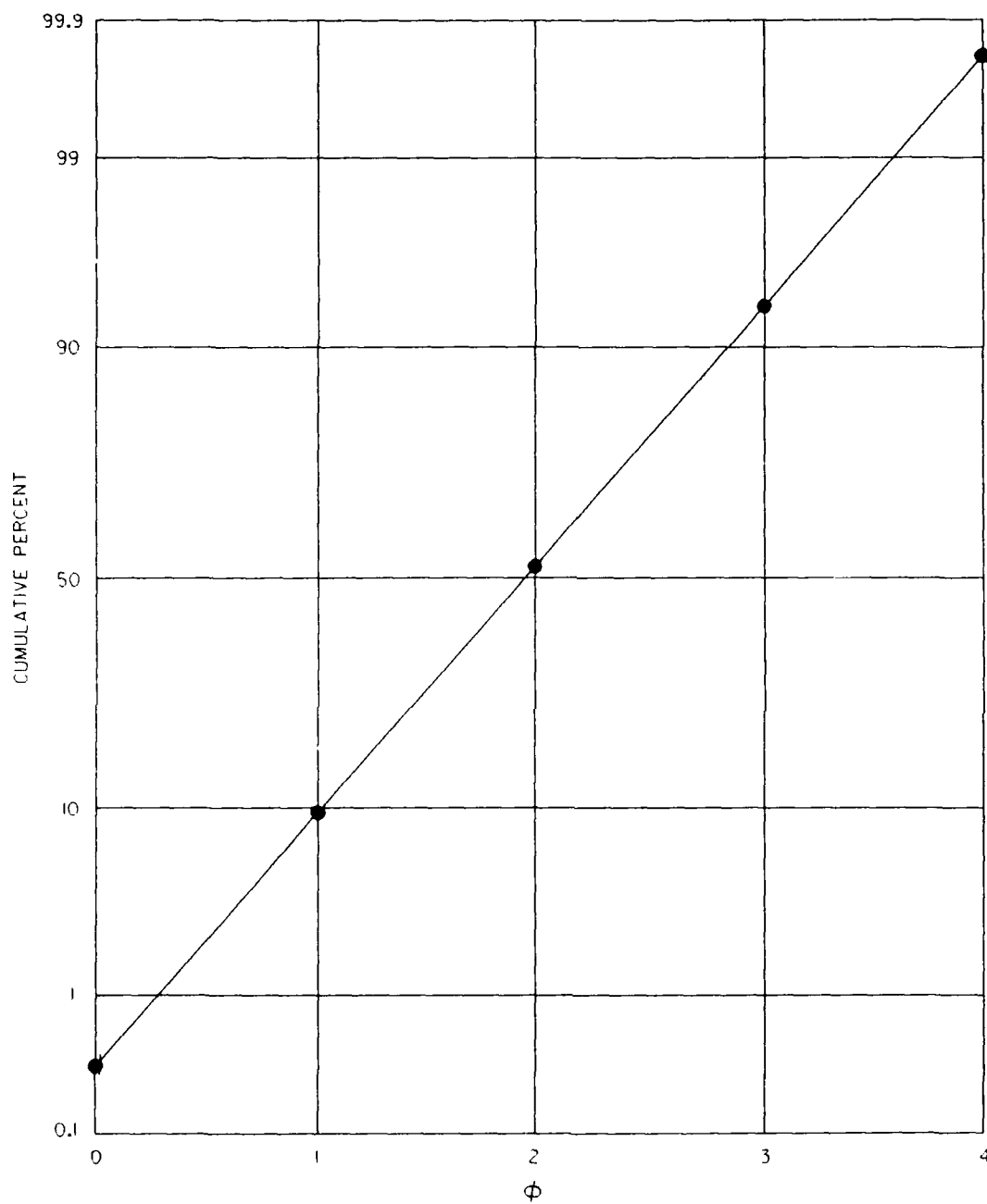


Figure 31. Cumulative curve, probability ordinate

Cumulative Curve - Arithmetic Ordinate

The cumulative curve plotted against an arithmetic ordinate is commonly used. The ordinate (vertical) is arithmetic running from 0 to 100 percent, while the abscissa in phi units begins with the small units (coarse material) to the left and moves toward finer materials (large phi units) to the right (Figure 30). It is now possible to plot the cumulative percentages of the sediment on this graphic preparation. For example, if 20 percent of the sediment sample is coarser than 2 phi, a point is placed on ordinate 20 and abscissa 2. After all data points are entered, a line is drawn through them to form a more or less S-shaped curve. It should be based on one-phi or less analysis of sieving (Folk 1974).

Cumulative Curve - Probability Ordinate

The cumulative curve plotted against a probability ordinate (on standard probability-90 paper) permits one to read off statistical parameters with greater accuracy since it normally plots as a straight line (Figure 31). The same phi units are used on the abscissa, but the ordinate is stretched out at the ends (curves of the S-curve) and condensed or shortened in the middle, resulting in a straight line (or nearly so under most conditions). The position of the line reflects the average particle size, and its slope depends upon the degree of sorting.

Some survey investigators may wish to construct a cumulative probability curve first and then transcribe the easily read data points on arithmetic base paper.

Method of Moment

The graphical techniques were devised in the precomputer age when calculation of these statistics by hand was quite difficult. They use only a few points from the graph to quantify a sample. The method of moment uses all the sample data points (sieve weights) to calculate the statistics, which is much more accurate, especially in cases of bimodal distribution. With the advent of computers, calculation of moment measures has become trivial and should be used in all cases. Software programs are readily available to perform the calculation (i.e., ISAP--Interactive Sediment Analysis Program)(Anders et al., in preparation). For those without ready access to computers and/or the necessary software, the computational procedures are given below.

Graphic Mean

A number of statistical parameters can be read from the plotted curves. Among them are the mode, median, and mean. The mode is the most common grain diameter; it is not frequently used. The median is not frequently used, but it indicates the point at which half of the particles by weight are coarser than the median and half are finer. Of greater usefulness is the graphic mean, which gives one an overview of particular sizes. It is calculated as

$$\text{Graphic mean} = \frac{\Phi_{16} + \Phi_{50} + \Phi_{84}}{3}$$

Mode

The mode is the grain size of the sample that has the highest population or occurs most frequently. It is best to determine the mode by trial and error. To do this one must inspect the cumulative probability curve and the inflection point, select the assumed location of the mode, and **measure the percentage of the sample** that falls within the grain size from 0.25Φ unit coarser than that point to 0.25Φ unit finer than that point. Then, move over 0.1Φ unit to a new potential mode location and measure the percentage of the sample within the 0.5Φ interval as above with the new mode as the center. This process is continued until the highest percentage is found. The center point of the largest percentage range is the modal diameter.

A sediment sample may have more than one inflection point, i.e., more than one mode. This parameter can be valuable in determining transport; ordinarily it remains fairly constant.

Inclusive Graphic Standard Deviation

This is the best available method for measuring the **uniformity** or sorting of sediments. It is derived from the cumulative curve as

$$\frac{\Phi_{84} - \Phi_{16}}{4} + \frac{\Phi_{95} - \Phi_5}{6.6}$$

Well-sorted sediments should have a value of 0.35Φ , whereas poorly sorted sediments would be 4.0Φ or more.

Inclusive Graphic Skewness - Optional

This is a good measure of the degree of asymmetry of the curve of grain size distribution

$$\frac{\Phi_{16} + \Phi_{84} - 2\Phi_{50}}{2(\Phi_{84} - \Phi_{16})} + \frac{\Phi_5 + \Phi_{95} - 2\Phi_{50}}{2(\Phi_{95} - \Phi_5)}$$

The skewness term is either positive or negative. Those samples with abnormal fine material (curve has a tail to the right) have positive skewness, whereas those with excess coarse material (tail to left) have negative skewness.

Kurtosis or Peakedness - Optional

If the curve of the particular sediment sample under study at the moment is a straight line on the **probability** graph, its constituents follow a normal curve. This can be checked by noting that if it is a normal curve, the following phi diameter intervals have the following relationship:

$$\text{Graphic kurtosis (GK)} = \frac{\Phi_{95} - \Phi_5}{2.44(\Phi_{75} - \Phi_{25})}$$

For normal curves $GK = 1.00$. If the curve is very peaked (leptokurtic), it will have a GK over 1.00. This means it is better sorted, i.e., it has a better dispersion. When the tails

of the curve have a small spread, they are said to be platykurtic and can be expected to have a GK under 1.00. Most sediments have GKs at some point between 0.85 and 1.5.

Plot of Station Sediments on Ternary Diagram

To classify sediments by name and to depict the relationships between the mean sediment type found at sampling stations, one may utilize plots on a triangular diagram, as shown in Figure 32. The station locations can be plotted knowing any two percentages, e.g., sand:silt, sand:clay, silt:clay. The example given in Figure 32 indicates that the material being dumped is finer grained than that at either the upcurrent or downcurrent stations. It would appear that the upcurrent stations, which have higher percentages of sand, represent the indigenous mean surficial sediment type, and that the downcurrent stations have acquired a fine component as a result of dumping and transport of clay-size grains.

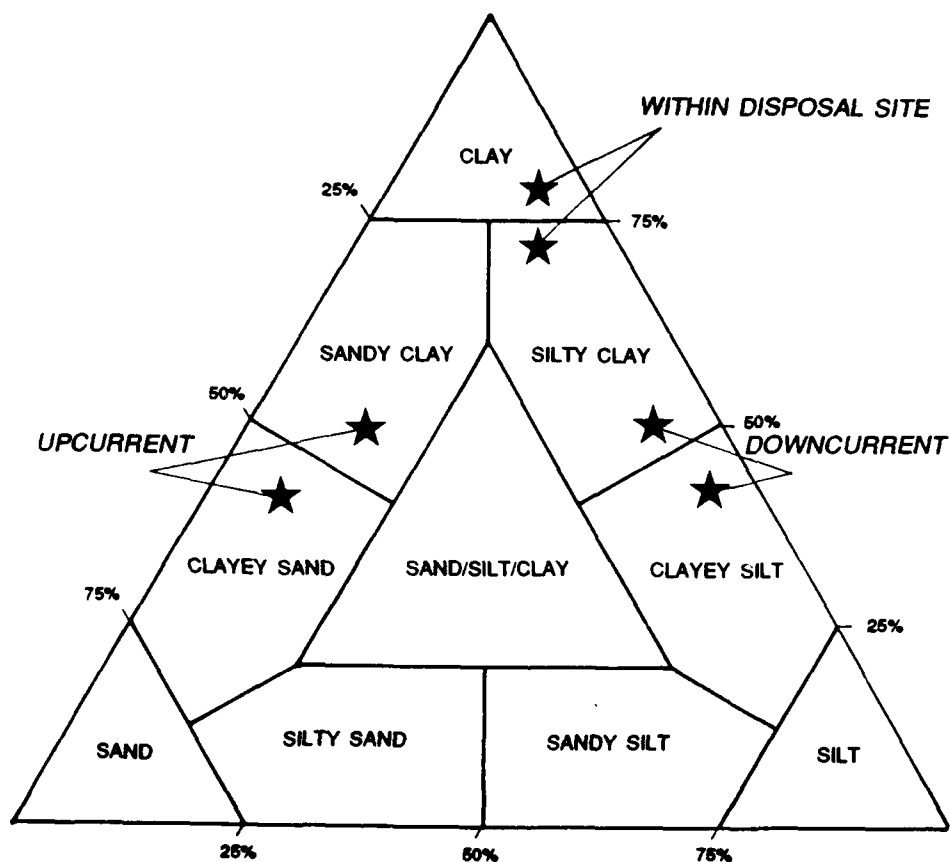


Figure 32. Surficial sediment analysis (top 5 cm) at the six stations (stars) plotted on a standard ternary diagram

Chemical Pollutants in the Sediments

Data from chemical pollutants contained in the surficial sediments should be presented in tabular form and also plotted on a simple line drawing of the disposal site and

contiguous areas, much as in Figure 33. Data from the seasonal samples as well as from monitoring should be plotted on the same map in order to portray any trends that are present.

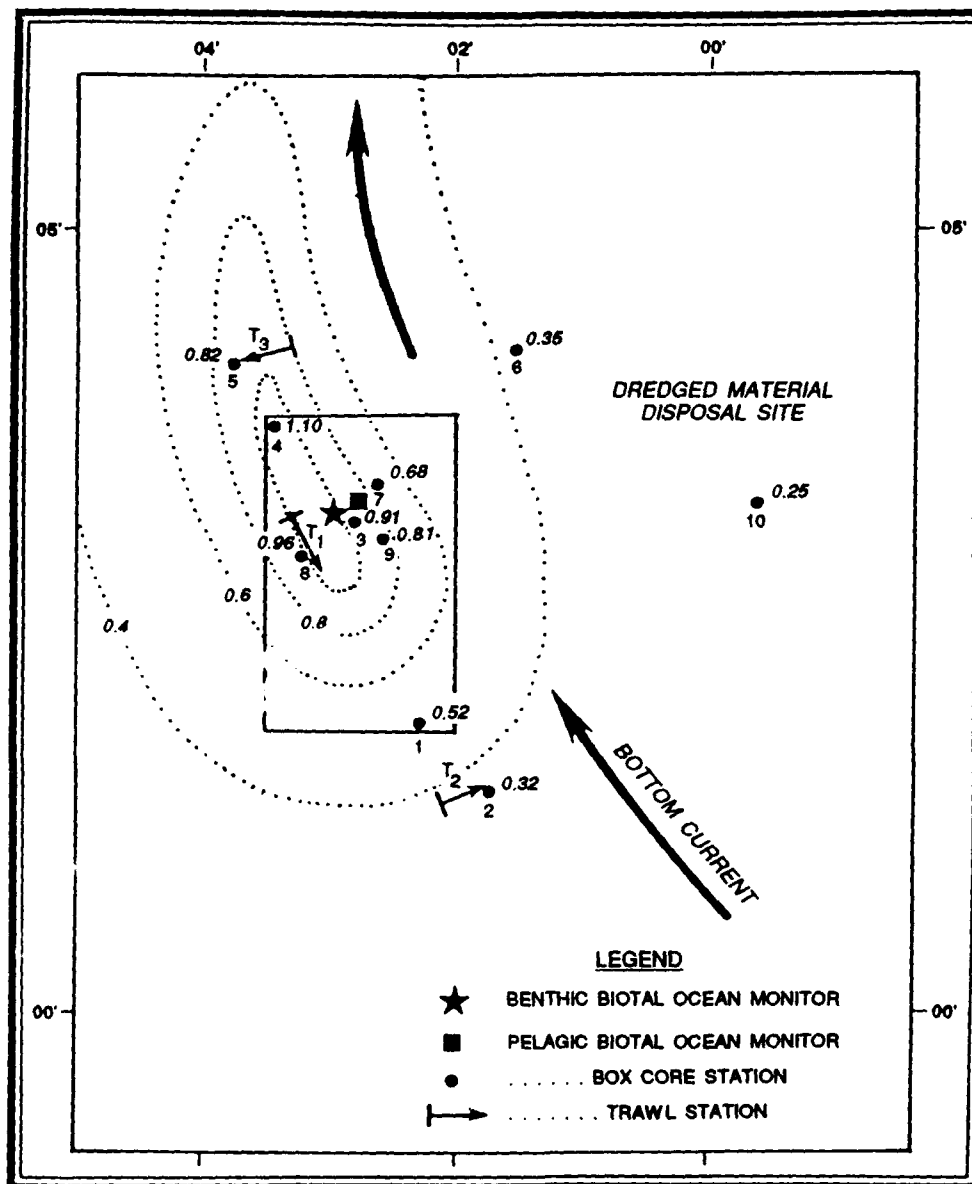


Figure 33. Example of data presentation for a chemical pollutant collected with a box corer. Hypothetical values for cadmium levels (in ppm) are shown in italics

ANALYSIS OF ENVIRONMENTAL DATA

Above we have described various first-order approaches to tabulating and graphically portraying environmental data describing sampling sites in terms of their physical and chemical attributes. These attributes represent habitat factors acting upon the resident

biota. As part of the disposal site selection process, it is important to quantitatively classify these benthic habitats in terms of their physical/chemical attributes as a first step toward determining the relationship of the resident benthic biota to the local environments--especially to factors that may be subject to change from dredged material disposal (e.g., sediment grain size, trace metals, etc.). Very often, a large suite (20 to 50 variables) of environmental measures are available. For example, these might include bottom water attributes (temperature, salinity, dissolved oxygen, etc.), sediment grain size information, trace metal and other contaminant concentrations in sediment and water such as PCBs, pesticides, oil and grease levels, and so on. Many of these factors are correlated, making comparisons difficult.

Principal Component Analysis

A quantitative means of making site evaluations is Principal Component Analysis (PCA). All of the environmental or habitat variables that were measured as potential factors affecting biota can be used in the analysis. The PCA enables one to transform a large original set of variables into a smaller set of combinations that account for most of the variance of the larger, original set. The purpose is to explain as much of the total variation in the data as possible, with as few of these factors as possible. The output of PCA enables one to group entities (in this case, sampling sites) in terms of their physical/chemical attributes. This, in effect, provides an environmental classification against which one can compare results of various biological classifications of the same stations. The question that is being addressed by this approach is: Do the distribution and abundance patterns of biota correspond to synoptic environmental differences?

A review of the PCA and how the statistics are computed can be found in virtually any multivariate statistics textbook (e.g., Cooley and Lohnes 1971). Fortunately, a number of programs for this analysis are available for almost any computer to which one may have access, ranging from PC's to micro- to mini- to mainframe computers. For example, SYSTAT, Inc., provides a statistical software package (including PCA) that is compatible for use in both IBM and compatibles and Apple Macintosh microcomputers. For mainframe computers, a variety of software options are available, including SAS and BMPD. These software programs are user-friendly, i.e., with interactive, menu-driven procedures.

Data Entry and Analysis

Typically, the input data are organized for input in a station by response variable matrix or table. The outputs include a list of principal components (groups of variables) and the amount of sample variance each component explains. Usually two to three of the components account for a high proportion of the overall variance. The relative weight of each variable or factor combined in a component is also provided. Ultimately, the components are used to ordinate the relative location of each of the entities (stations) when plotted against two factors. Station groupings appear based upon similarities of the environment. These groupings represent different habitats based upon the array of variables measured.

An example of the ultimate output is provided in Figure 34. Here, two components of a 40-variable data set explained 63 percent of the overall variance. Gallaway, Martin, and Howard (1988) interpreted the results to show five station groups, or habitats, which generally corresponded to three depth categories. It should be noted that depth was not used as an input variable. Levels of hydrocarbons in the sediments, percent clay, and

bottom temperature comprised one component that explained 40 percent of the sample variance. The other component explained 23 percent of the sample variance and included as major factors bottom water levels of salinity and dissolved organic carbon and levels of calcium carbonate and sand in the sediments.

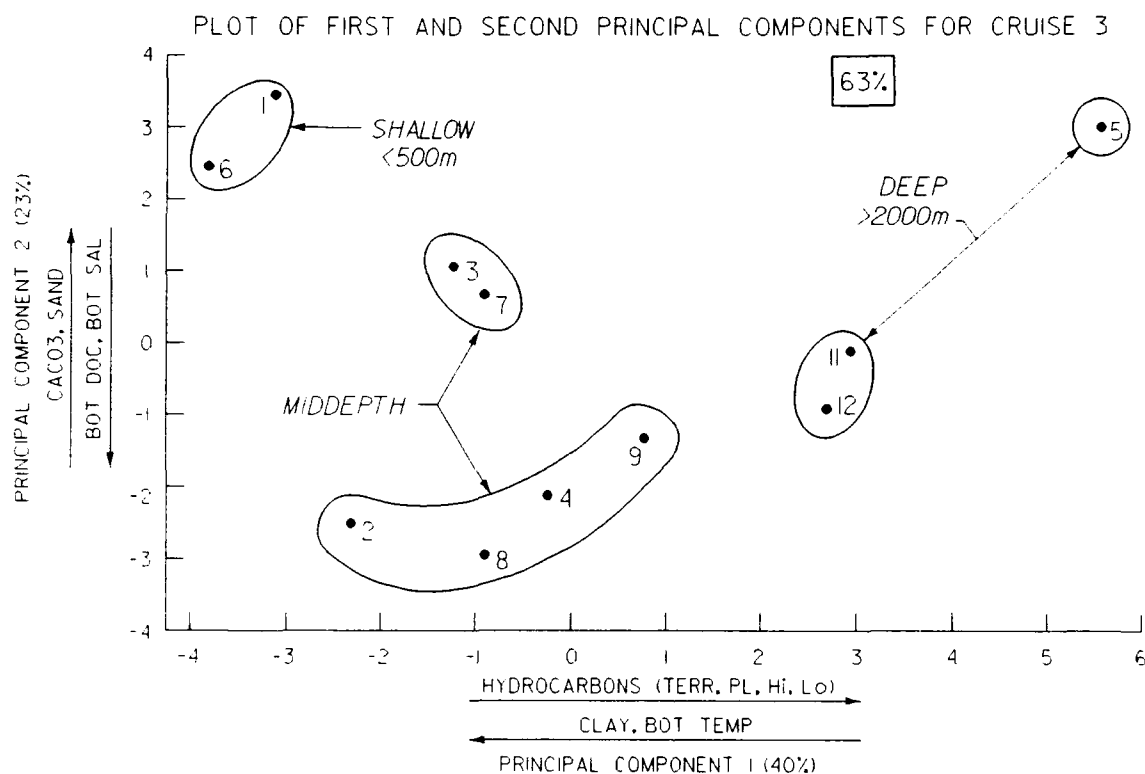


Figure 34. Results of Principal Component Analysis of physical/chemical variables showing similarities of Stations C2-C12 sampled during Cruise III, fall 1984 (after Gallaway, Martin, and Howard 1988)

ANALYSIS OF DATA ON BENTHIC BIOTA

What the Sample Represents

Effective sampling of populations of benthic organisms is very difficult to achieve. The range of size from a few microns to a meter or more, and of mobility from languid burrowers to fast-moving crabs and demersal fishes, is such that no single sampling device can be expected to work equally well for all ecological types. Even when one is sampling for a single type, say, the macroinfaunal species that live within the sediments, the dispersion of individuals may be clumped or patchy rather than random or even. As a result some attempts to sample will yield negative results, making it necessary to take a series of replicates at a station if one is to obtain a representative sample. The term representative sample in this context means the real populations from which the samples were taken; hence, a sufficient number of individual samples must be taken to permit use of sample statistics to estimate real population statistics. Thus, it may take a series of individual samples to give the composite representative sample.

Population Statistics

In a given region, all of the individuals of a species in which there is a critical interest comprise the population of that species. Obviously, this is an imaginative abstraction because what space the species occupies is not known; hence, one seeks to determine its average density, i.e., the number of individuals per some unit of area (e.g., per square meter). If only a single sample is taken, the ability to judge how representative the sample is is limited. But when several replicates are taken at each of several stations, certain statistical parameters can be employed to evaluate the reliability of the estimates. A simple but very valuable first step is to calculate the arithmetic mean, which is the sum of all the individuals collected divided by the number of samples. Knowing the area of the sampler, one can multiply to come up with the average density per square meter. The mean also represents the center of the observations in the samples, and thus it is the starting point of the analysis of the spread of values. The first step here is to observe the range of the number of individuals taken per sample from highest to lowest. When the population of a species is clumped, the range will usually be large. Thus, if several values are available, it is advisable to calculate the variance and standard deviation, which weights each sample value by its distance from the mean (center). The variance is the sum of squared deviations from the mean divided by the number of samples less one (degrees of freedom). The standard deviation is derived by taking the square root of the variance. For a discussion, consult a standard textbook of statistics, such as **Biometry** (Sokal and Rohlf 1969).

Community Statistics

Thus far, only the populations of the species have been considered. Seldom will the ocean surveys be limited to interest in single species. Rather, researchers want to consider groups of species, which may loosely be called communities. For this study's purposes, then, a community may be considered as consisting of the populations of several species. One is also interested in species richness and how individuals are distributed among the component species (equitability). Also, one may wish to know to what extent the samples represent all of the species of a community, and it may be useful to determine how closely total samples are related and to place closely related stations in discrete groups. Since communities are comprised of individual species, some of the statistics developed for populations can be used, but the more complex aspects of community structure will require different statistical techniques. Accordingly, let us start first with population statistics and apply it to the macroinfauna.

Presentation of Population Data on Macroinfauna

The major components of the macroinfauna, which live in the sediments and are retained on a 0.5-mm sieve, are generally polychaete annelid worms, bivalve molluscs, and various crustaceans such as amphipods and isopods. The most appropriate device for sampling the macroinfauna is either a box corer (see Figure 23) of appropriate size (say, taking a 30- by 30-cm area of the bottom sediments) or a Smith-McIntyre grab. Much of the population data derived for the macroinfauna can be presented very effectively in tabular form (Table 27).

The following calculations are based on data for *Polychaete* sp. A in Table 27. Five replicate box corer samples have been taken of the macroinfauna at a particular station.

Table 27
Tabulation of Population Values for Five Macroinfaunal Species

Species	Individual (x)					Total	Mean	95% Confidence Limits of Mean	Standard Deviation	Coefficient of Dispersion	Species Rank	Percent of Total	Cumulative Percent
	1	2	3	4	5								
Polychaete A	140	110	80	40	105	475	95	48.6 - 141.4	37.42	14.74	1	57	57
Polychaete B	65	75	50	35	60	285	57	38.1 - 75.9	15.25	4.08	2	34	91
Bivalve 1	15	12	8	4	6	45	9	3.5 - 14.6	4.47	2.22	3	5	96
Amphipod A	10	4	3	2	6	25	5	0.2 - 9.8	3.87	3.00	4	3	99
Bivalve 2	3	0	1	0	1	5	1	0.0 - 1.5	1.20	1.50	5	1	100
Total	233	201	142	81	178	835	167						
Number of Species	5	4	5	4	5	5							

After sieving the sediment through a nest of sieves, the smallest mesh of which is 0.5 mm, the retained organisms are sorted and the number of individuals of each selected species enumerated. After tabulating the data, a useful statistic to calculate is the standard deviation (a measure of dispersion) as is shown stepwise below.

- a. First, find the mean $\bar{x} = \frac{\Sigma x}{n} = \frac{475}{5} = 95$
- b. Find the deviation of each sample from the mean $x = X - \bar{x} = +45, +15, -55, +10$
- c. Square each deviation $x^2 = (X - \bar{x})^2 = \begin{array}{r} 2,025 \\ 225 \\ 225 \\ 3,025 \\ 100 \end{array}$
- d. Find the sum of the squared deviations (sum of squares) $\Sigma x^2 = \Sigma (x - \bar{x})^2 = 5,600$
- e. Divide the sum of squares by the degrees of freedom $\sigma^2 = \frac{\Sigma x^2}{n - 1} = \frac{5,600}{4} = 1,400$
- f. Extract the square root to find the standard deviation $\sigma = \sqrt{\frac{\Sigma x^2}{n - 1}} = 37.42$

Based on the nature of the normal curve, 68 percent of the samples should have values falling between plus or minus one standard deviation from the mean, which in this case is

$$95 + 37.42 = 132.42, \text{ and}$$

$$95 - 37.42 = 57.58$$

It is usually expected that one will calculate confidence limits of the mean at the 95-percent level. In other words, this means that one can be 95 percent sure that the true population mean lies between the confidence limits. This parameter is calculated from the standard deviation, the number of samples, and the value of t , which can be found in any statistics text (see Table 28).

Table 28
Distribution of t*

Degrees of Freedom	Probability of a Larger Value, Sign Ignored								
	0.500	0.400	0.200	0.100	0.050	0.025	0.010	0.005	0.001
1	1.000	1.376	3.078	6.314	12.706	25.452	63.657		
2	0.816	1.061	1.886	2.920	4.303	6.205	9.925	14.089	31.598
3	0.765	0.978	1.638	2.353	3.182	4.176	5.841	7.453	12.941
4	0.741	0.941	1.533	2.132	2.776	3.495	4.604	5.598	8.610
5	0.727	0.920	1.476	2.015	2.571	3.163	4.032	4.773	6.859
6	0.718	0.906	1.440	1.943	2.447	2.969	3.707	4.317	5.959
7	0.711	0.896	1.415	1.895	2.365	2.841	3.499	4.029	5.405
8	0.706	0.889	1.397	1.860	2.306	2.752	3.355	3.832	5.041
9	0.703	0.883	1.383	1.833	2.262	2.685	3.250	3.690	4.781
10	0.700	0.879	1.372	1.812	2.228	2.634	3.169	3.581	4.587
11	0.697	0.876	1.363	1.796	2.201	2.593	3.106	3.497	4.437
12	0.695	0.873	1.356	1.782	2.179	2.560	3.055	3.428	4.318
13	0.694	0.870	1.350	1.771	2.160	2.533	3.012	3.372	4.221
14	0.692	0.868	1.345	1.761	2.145	2.510	2.977	3.326	4.140
15	0.691	0.866	1.341	1.753	2.131	2.490	2.947	3.286	4.073
16	0.690	0.865	1.337	1.746	2.120	2.473	2.921	3.252	4.015
17	0.689	0.863	1.333	1.740	2.110	2.458	2.898	3.222	3.965
18	0.688	0.862	1.330	1.734	2.101	2.445	2.878	3.197	3.922
19	0.688	0.861	1.328	1.729	2.093	2.433	2.861	3.174	3.883
20	0.687	0.860	1.325	1.725	2.086	2.423	2.845	3.153	3.850
21	0.686	0.859	1.323	1.721	2.080	2.414	2.831	3.135	3.819
22	0.686	0.858	1.321	1.717	2.074	2.406	2.819	3.119	3.792
23	0.685	0.858	1.319	1.714	2.069	2.398	2.807	3.104	3.767
24	0.685	0.857	1.318	1.711	2.064	2.391	2.797	3.090	3.745
25	0.684	0.856	1.316	1.708	2.060	2.385	2.787	3.078	3.725
26	0.684	0.856	1.315	1.706	2.056	2.379	2.779	3.067	3.707
27	0.684	0.855	1.314	1.703	2.052	2.373	2.771	3.056	3.690
28	0.683	0.855	1.313	1.701	2.048	2.368	2.763	3.047	3.674
29	0.683	0.854	1.311	1.699	2.045	2.364	2.756	3.038	3.659
30	0.683	0.854	1.310	1.697	2.042	2.360	2.750	3.030	3.646
35	0.682	0.852	1.306	1.690	2.030	2.342	2.724	2.996	3.591
40	0.681	0.851	1.303	1.684	2.021	2.329	2.704	2.971	3.551
45	0.680	0.850	1.301	1.680	2.014	2.319	2.690	2.952	3.520
50	0.680	0.849	1.299	1.676	2.008	2.310	2.678	2.937	3.496
55	0.679	0.849	1.297	1.673	2.004	2.304	2.669	2.925	3.476
60	0.679	0.848	1.296	1.671	2.000	2.299	2.660	2.915	3.460
70	0.678	0.847	1.294	1.667	1.994	2.290	2.648	2.899	3.435
80	0.678	0.847	1.293	1.665	1.989	2.284	2.638	2.887	3.416
90	0.678	0.846	1.291	1.662	1.986	2.279	2.631	2.878	3.402
100	0.677	0.846	1.290	1.661	1.982	2.276	2.625	2.871	3.390
120	0.677	0.845	1.289	1.658	1.980	2.270	2.617	2.860	3.373
∞	0.6745	0.8416	1.2816	1.6448	1.9600	2.2414	2.5758	2.8070	3.2905

* Reprinted by permission from Snedecor and Cochran (1956). Portions reprinted by permission from R.A. Fisher's *Statistical Methods for Research Workers*, published by Oliver and Boyd, Edinburgh (1925-1950); from Maxine Merrington's "Table of Percentage Points of the t-Distribution," *Biometrika*, 32:300 (1942); and from Bernard Ostle's *Statistics in Research*, Iowa State College Press (1954).

$$\text{Percent confidence limit} = \frac{t\sigma}{\sqrt{n}} = \frac{2.78 \times 37.42}{2.24} = \frac{104.03}{2.24} = 46.44$$

This means that there is only 1 chance in 20 that one would be wrong if one assumes the true population mean lies between 141.44 and 48.56. The spread is very large because of the small number of samples and the patchy nature of distribution of Polychaete sp. A in the sediments. One can always infer that this nonrandom distribution occurs when the variance is substantially larger than the mean (in this case 1,400 versus 95). This can be regularized by calculating another parameter--the coefficient of dispersion.

The coefficient of dispersion (CD) is simply the ratio between the variance and the mean.

$$CD = 1,400:95 = 14.74$$

Random distribution	CD = 1
Clumped (patchy)	CD = >1
Even	CD = <1

From this it is concluded that the individuals of Polychaete sp. A with a CD of 14.74 are strongly clumped and possibly have what one might call "contagious" distribution, i.e., that the presence of one individual serves as a strong attractant for another, and the two for yet another, etc.

The above findings regarding the macroinfaunal species populations can be applied to a monitoring program in the following ways. First, the monitoring sampling would be done with the same collecting gear, at the same stations, and as near as feasible to the same period of year as the baseline survey. Then one would

- Record changes, if any, in species richness--particularly absences of species and the appearance of species that were previously not present.
- Note whether the predominant species have changed, i.e., whether the structure of the community shifted.
- Note whether the mean values for each species and the sum of the means for the predominant species are the same or different. The difference should be tested statistically for significance.

Unless these changes are large, they may be obscured by natural fluctuations in the biota.

Test of the significance of the difference between two means

Suppose the results of sampling Polychaete sp. A during the baseline and monitoring surveys are compared for the significance of the difference. This can be done by ANOVA (analysis of variance for two groups) or by the t-test of the differences between two means. Since many investigators are more familiar with it than with ANOVA, this study will use the t-test. Perhaps it should be added that they are equivalent mathematically.

Box Core Number	Polychaete sp. A Number in Core	
	Baseline Survey	Monitoring Survey
1	140	110
2	110	105
3	80	45
4	40	50
5	<u>105</u>	<u>115</u>
Totals	475	425
Mean (x)	95	85
Standard Deviation	37.4	34.4
Coefficient of Dispersion	14.74	13.97

The baseline survey at the test station has a mean number of individuals of Polychaete sp. A of 95 with a standard deviation of 37.4 individuals, and five samples from the same station during the monitoring survey yielded a mean number of individuals of Polychaete sp. A of 85 with a standard deviation of 34.4 individuals. It is anticipated that using the t-test will determine the significance of the observed difference. But before calculation of t, it is necessary to ascertain if the variances of the two sets of data are homogeneous. For this purpose, one may employ Cochran's test for the homogeneity of variances in which the test C is solved as the ratio of the largest variance to the sum of all variances.

$$C = \frac{\sigma^2_{\max}}{\Sigma \sigma^2} = \frac{1,400}{2,587.5} = 0.54$$

This value of C is interpreted by comparing it to the table of C values (Table 29). In the table, k is the number of sample variances summed in the denominator, and v is one less than the number of samples contributing to each variance. The tabulated value of C is 0.7679. Since the calculated C-value (0.54) is smaller than the tabular C-value, the calculated value is not significant at the 95-percent confidence level, and the variances may be considered homogeneous. If the calculated C-value is larger than the tabulated, the variances are not homogeneous. In this event the data must be transformed in order to equalize the variances. Among the three common transformations, the most frequently used is the logarithmic transformation using common logarithms log (x); if zero counts are involved, log (x + 1) is used. Then one finds the C-value of the transformed data. If the variances are now homogeneous, the transformed data are used in deriving the t-test or analysis of variance to test significance. To report these data, the means are transformed back to the linear scale by finding their antilogarithms.

Student t-test

Since the variances between the baseline and monitoring surveys were found to be homogeneous, one is now ready to test significance of mean differences with the t-test (other tests of significance may be used).

Comparing the $t = 0.44$ with the tabulated value with 8 df and +0.05, a value of 2.306 is found (Table 28). Since the calculated t-value is less than the tabulated, the difference

Table 29
Critical Values for Cochran's Test*

Values given are for the statistic $\frac{(\text{largest } s_i^2)}{k} \sum_{i=1}^k s_i^2$, where each of the k values of s_i^2 has n degrees of freedom.

$\frac{n}{k}$	Percentile 95														
	$\frac{1}{-}$	$\frac{2}{-}$	$\frac{3}{-}$	$\frac{4}{-}$	$\frac{5}{-}$	$\frac{6}{-}$	$\frac{7}{-}$	$\frac{8}{-}$	$\frac{9}{-}$	$\frac{10}{-}$	$\frac{16}{-}$	$\frac{36}{-}$	$\frac{144}{-}$	∞	
2	0.9985	0.9750	0.9392	0.9057	0.8772	0.8534	0.8332	0.8159	0.8010	0.7880	0.7341	0.6602	0.5813	0.5000	
3	0.9669	0.8709	0.7977	0.7457	0.7071	0.6771	0.6530	0.6333	0.6167	0.6025	0.5466	0.4748	0.4031	0.3333	
4	0.9065	0.7679	0.6841	0.6287	0.5895	0.5598	0.5365	0.5175	0.5017	0.4884	0.4366	0.3720	0.3093	0.2500	
5	0.8412	0.6838	0.5981	0.5441	0.5065	0.4783	0.4564	0.4387	0.4241	0.4118	0.3645	0.3066	0.2513	0.2000	
6	0.7808	0.6161	0.5321	0.4803	0.4447	0.4184	0.3980	0.3817	0.3682	0.3568	0.3135	0.2612	0.2119	0.1667	
7	0.7271	0.5612	0.4800	0.4307	0.3974	0.3726	0.3535	0.3384	0.3259	0.3154	0.2756	0.2278	0.1833	0.1429	
8	0.6798	0.5157	0.4377	0.3910	0.3595	0.3362	0.3185	0.3043	0.2926	0.2829	0.2462	0.2022	0.1616	0.1250	
9	0.6385	0.4775	0.4027	0.3584	0.3286	0.3067	0.2901	0.2768	0.2659	0.2568	0.2226	0.1820	0.1446	0.1111	
10	0.6020	0.4450	0.3733	0.3311	0.3029	0.2823	0.2666	0.2541	0.2439	0.2353	0.2032	0.1655	0.1308	0.1000	
12	0.5410	0.3924	0.3264	0.2880	0.2624	0.2439	0.2299	0.2187	0.2098	0.2020	0.1737	0.1403	0.1100	0.0833	
15	0.4709	0.3346	0.2758	0.2419	0.2195	0.2034	0.1911	0.1815	0.1736	0.1671	0.1429	0.1144	0.0889	0.0667	
20	0.3894	0.2705	0.2205	0.1921	0.1735	0.1602	0.1501	0.1422	0.1357	0.1303	0.1108	0.0879	0.0676	0.0500	
24	0.3434	0.2354	0.1907	0.1656	0.1493	0.1374	0.1286	0.1216	0.1160	0.1113	0.0942	0.0743	0.0567	0.0417	
30	0.2929	0.1980	0.1593	0.1377	0.1237	0.1137	0.1061	0.1002	0.0958	0.0921	0.0771	0.0604	0.0457	0.0333	
40	0.2370	0.1576	0.1259	0.1082	0.0968	0.0887	0.0827	0.0780	0.0745	0.0713	0.0595	0.0462	0.0347	0.0250	
60	0.1737	0.1131	0.0895	0.0765	0.0682	0.0623	0.0583	0.0552	0.0520	0.0497	0.0411	0.0316	0.0234	0.0167	
120	0.0998	0.0632	0.0495	0.0419	0.0371	0.0337	0.0312	0.0292	0.0279	0.0266	0.0218	0.0165	0.0120	0.0083	
∞	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

* By permission from C. Eisenhart, M. W. Hastay, and W. A. Wallis, *Techniques of Statistical Analysis*, Chap. 15. McGraw-Hill Book Company, New York, 1947.

between the mean is not significant. Thus, it can be concluded that the population of Polychaete sp. A has not changed significantly in the interval between baseline and monitoring surveys at the collecting station involved.

Box Core Replicates	Population Numbers of Polychaete sp. A	
	Baseline Survey (x)	Monitoring Survey (x)
1	140	110
2	110	105
3	80	45
4	40	50
5	<u>105</u>	<u>115</u>
Σx	475	425
$\bar{x} = \frac{\Sigma x}{N} =$	95	85
Sum of squares $SS = \Sigma(x - \bar{x})^2 =$	5,600	4,750
Variance $\sigma^2 = \frac{SS}{n - 1} =$	1,400	1,187.50
$t = \frac{\bar{x}_b - \bar{x}_m}{\sqrt{\sigma_b^2 + \sigma_m^2}} = \frac{95 - 85}{\sqrt{\frac{1,400 + 1,187.50}{5}}} = \frac{10}{\sqrt{517.50}} =$	0.44	

Analysis of variance

The t-test of significance is satisfactory for any situation that involves only two groups and a test of the difference between their means. However, when testing of three or more groups is desired, analysis of variance is used. Before resorting to ANOVA to analyze data from field studies, one should give consideration to the comments of Hurlbert (1984) and Stewart-Oaten, Murdoch, and Parker (1986) in regard to its application to impact studies. The principal concern expressed in these papers is that when applied improperly, ANOVA may lead to the conclusion of an impact when in fact no impact has occurred. The t-test could still be used with three groups to evaluate the difference between the means by comparing 1 and 2, 2 and 3, and 1 and 3. The ANOVA permits testing of differences among all of the means at the same time, and its test of significance is the so-called F-distribution.

Suppose, for example, one wishes to compare the means for a given species from samples taken at the dredged material site, at a downstream site, and upstream of the site. Using Bivalve sp. 1 as the test organism, its population values in five replicate box cores at the three locations are shown in Table 30.

Table 30
Individuals of Bivalve sp. 1 Taken in Five Replicate Box Cores at Three Stations
(All Samples = N)

<u>Disposal Site (N1)</u>		<u>Downstream Site (N2)</u>		<u>Upstream Site (N3)</u>	
<u>x</u>	<u>x²</u>	<u>x</u>	<u>x²</u>	<u>x</u>	<u>x²</u>
2	4	4	16	7	49
2	4	6	36	10	100
3	9	7	49	10	100
7	49	9	81	11	121
<u>6</u>	<u>36</u>	<u>9</u>	<u>81</u>	<u>12</u>	<u>144</u>
20	102	35	263	50	514

The basic assumption (called the null hypothesis) is that the three groups of samples are random samples collected from a normally distributed population. Two estimates of the population variance are calculated: a sum of squares based upon variation within the three groups, and a sum of squares based upon the variation between the group means. The two estimates of the population variance may be expected to differ only within the limits of random sampling. The null hypothesis is tested by dividing the larger variance by the smaller variance to get the variance ratio; the 5- and 1-percent points of the variance ratio are called *F*, the values for which are found in Table 31. If the observed *F*-value equals or exceeds the table value, the null hypothesis is rejected, and it may be concluded that the samples were not drawn from the same common normal population. In this case, the populations from which the samples were drawn may differ in terms of means or variances or both. If the variances are about the same, it is the means that differ significantly.

To calculate ANOVA:

- a. Calculate the total sum of squares (SS) $\Sigma(x - \bar{x})^2$

$$\sum_{i=1}^n x^2 - \frac{(\sum x)^2}{n} \quad n = \text{samples}$$

Taking the values from Table 30 gives

$$\begin{aligned} \Sigma(x - \bar{x})^2 &= 879 - \frac{(105)^2}{15} \\ &= 879 - 735 \end{aligned}$$

Total sum
of squares = 144

Table 31
The 5 (Roman Type) and 1 (Boldface Type) Percent Points for the Distribution of F*

n ₂	n ₁ , degrees of freedom (for greater mean square)																			∞	
	1	2	3	4	5	6	7	8	9	10	11	12	14	16	20	24	30	40	50		
1	161 4.052	200 4.999	216 5.403	225 5.625	230 5.764	234 5.859	237 5.928	239 5.981	241 6.022	242 6.056	243 6.082	244 6.106	245 6.142	246 6.169	248 6.208	249 6.234	250 6.258	251 6.286	252 6.302	253 6.323	254 6.352
2	18.51 98.49	19.00 99.00	19.16 99.17	19.25 99.25	19.30 99.30	19.33 99.33	19.36 99.34	19.37 99.36	19.38 99.38	19.39 99.40	19.40 99.41	19.41 99.42	19.42 99.43	19.43 99.44	19.44 99.45	19.45 99.46	19.46 99.47	19.47 99.48	19.47 99.48	19.48 99.49	19.49 99.49
3	10.13 34.12	9.55 30.82	9.28 29.46	9.12 28.71	9.01 28.24	8.94 27.91	8.88 27.67	8.84 27.49	8.81 27.34	8.78 27.23	8.76 27.13	8.74 27.05	8.71 26.92	8.69 26.83	8.66 26.69	8.64 26.60	8.62 26.50	8.60 26.41	8.58 26.35	8.57 26.27	8.54 26.18
4	7.71 21.20	6.94 18.80	6.59 16.69	6.39 15.98	6.26 15.52	6.16 15.21	6.09 14.98	6.04 14.80	6.00 14.66	5.96 14.54	5.93 14.45	5.91 14.37	5.87 14.24	5.84 14.15	5.80 14.02	5.77 13.93	5.74 13.83	5.71 13.74	5.70 13.69	5.68 13.61	5.64 13.52
5	6.61 16.26	5.79 13.27	5.41 12.06	5.19 11.39	5.05 10.97	4.95 10.67	4.88 10.45	4.82 10.27	4.78 10.15	4.74 10.05	4.70 9.96	4.68 9.89	4.64 9.77	4.60 9.68	4.56 9.55	4.53 9.47	4.50 9.38	4.46 9.29	4.44 9.24	4.42 9.17	4.37 9.04
6	5.90 13.74	5.14 10.92	4.76 9.78	4.53 9.15	4.39 8.75	4.28 8.47	4.21 8.26	4.15 8.10	4.10 7.98	4.06 7.87	4.03 7.79	4.00 7.72	3.96 7.60	3.92 7.52	3.87 7.39	3.84 7.31	3.81 7.23	3.77 7.14	3.75 7.09	3.72 7.02	3.68 6.90
7	5.59 12.25	4.74 9.55	4.35 8.45	4.12 7.85	3.97 7.46	3.87 7.19	3.79 7.00	3.73 6.84	3.68 6.71	3.63 6.62	3.60 6.54	3.57 6.47	3.52 6.35	3.49 6.27	3.44 6.15	3.41 6.07	3.38 5.98	3.34 5.90	3.32 5.85	3.29 5.78	3.24 5.70
8	5.32 11.26	4.46 8.65	4.07 7.59	3.84 7.01	3.69 6.63	3.58 6.37	3.50 6.19	3.44 6.03	3.39 5.91	3.34 5.82	3.31 5.74	3.28 5.67	3.23 5.56	3.20 5.48	3.15 5.36	3.12 5.28	3.08 5.20	3.05 5.11	3.03 5.06	3.00 5.00	2.96 4.91
9	5.12 10.56	4.26 8.02	3.86 6.99	3.63 6.42	3.48 6.06	3.37 5.80	3.29 5.62	3.23 5.47	3.18 5.35	3.13 5.26	3.10 5.18	3.07 5.11	3.02 5.00	2.98 4.92	2.93 4.80	2.90 4.73	2.86 4.64	2.82 4.56	2.80 4.51	2.77 4.45	2.72 4.36
10	4.96 10.04	4.10 7.56	3.71 6.55	3.48 5.99	3.33 5.64	3.22 5.39	3.14 5.21	3.07 5.06	3.02 4.95	2.97 4.85	2.94 4.78	2.91 4.71	2.86 4.60	2.82 4.52	2.77 4.41	2.74 4.33	2.70 4.25	2.67 4.17	2.64 4.12	2.61 4.05	2.55 3.96
11	4.84 9.65	3.98 7.20	3.59 6.22	3.36 5.67	3.20 5.32	3.09 5.07	3.01 4.88	2.95 4.74	2.90 4.63	2.86 4.54	2.82 4.46	2.79 4.40	2.74 4.29	2.70 4.21	2.65 4.10	2.61 4.02	2.57 3.94	2.53 3.86	2.50 3.80	2.47 3.74	2.42 3.66
12	4.75 9.33	3.88 6.93	3.49 5.95	3.26 5.41	3.11 5.06	3.00 4.82	2.92 4.65	2.85 4.50	2.80 4.39	2.76 4.30	2.72 4.22	2.69 4.16	2.64 4.05	2.60 3.98	2.54 3.86	2.50 3.78	2.46 3.70	2.42 3.61	2.40 3.56	2.36 3.49	2.32 3.41
13	4.67 9.07	3.80 6.70	3.41 5.74	3.18 5.20	3.02 4.86	2.92 4.62	2.84 4.44	2.77 4.30	2.72 4.19	2.67 4.10	2.63 4.02	2.60 3.96	2.55 3.85	2.51 3.78	2.46 3.67	2.42 3.59	2.38 3.51	2.34 3.42	2.32 3.42	2.28 3.30	2.26 3.27

* Reprinted by permission from Snedecor and Cochran (1956).

b. Next calculate the sum of squares within groups for the three sites (N1, N2, N3)

(1) Dredged material site

$$\begin{aligned} \sum_{N1} (x - \bar{x})^2 &= 102 - \frac{(20)^2}{5} \\ &= 102 - 80 \\ &= 22 \end{aligned}$$

(2) Downstream site

$$\begin{aligned} \sum_{N2} (x - \bar{x})^2 &= 263 - \frac{(35)^2}{5} \\ &= 263 - 245 \\ &= 18 \end{aligned}$$

(3) Upcurrent site

$$\begin{aligned} \sum_{N3} (x - \bar{x})^2 &= 514 - \frac{(50)^2}{5} \\ &= 514 - 500 \\ &= 14 \end{aligned}$$

$$\begin{aligned} \text{SS within} \\ \text{groups} &= 54 \end{aligned}$$

c. Next, find the sum of squares **between** groups (SSB)

$$\sum_{i=1}^3 N(\bar{x}_i - \bar{x})^2, \text{ where } \bar{x} \text{ is the mean of all samples (7)}$$

Thus far, the difference between total sum of squares and SS within groups is $144 - 54 = 90$. Thus, SSB must account for this.

(1) Dredged material site

$$\begin{aligned} \text{SSB} &= 5(4 - 7)^2 \\ &= 45 \end{aligned}$$

(2) Downcurrent site

$$\begin{aligned} \text{SSB} &= 5(7 - 7)^2 \\ &= 0 \end{aligned}$$

(3) Upcurrent site

$$\begin{aligned}SSB &= 5(10 - 7)^2 \\&= 45\end{aligned}$$

This gives us the 90 units of SS mentioned above.

d. This step involves deriving the degrees of freedom. Remembering that

$$\text{Total sum of squares} = \text{Within} + \text{Between}$$

Each of these sums has a specified number of degrees of freedom (df); for the total it is $N - 1$, which in this case is $15 - 1 = 14$; the df for within groups is derived as $k(N_i - 1) = 3 \text{ groups} (5 \text{ samples} - 1) = 3 \times 4 = 12$; the df for between groups is derived as $k(\text{number of groups}) - 1 = 2$. One now divides the SS **within** by its df, to get $(54/12) = 4.5$. This is an estimate of the common population variance independent of the variation in the group means. If one divides the SS **between** by its df ($90/2 = 45$), one has a second estimate of population variance that is independent of the variation within groups. In ANOVA these independent estimates of population variance are called mean squares.

All of the above is ordinarily tabulated as in Table 32.

Table 32
ANOVA of Populations of Bivalve sp. 1 from the Upcurrent,
Downcurrent, and Disposal Site Station

<u>Variation</u>	<u>Sum of Squares</u>	<u>df</u>	<u>Mean Squares</u>
Between groups	90	2	45.0
Within groups	<u>54</u>	<u>12</u>	4.5
Total	144	14	

e. The final and most critical step is testing the significance of the ANOVA calculations, by finding F .

$$F = \frac{\text{mean square between groups}}{\text{mean square within groups}}$$

From the data in Table 32,

$$F = \frac{45.0}{4.5} = 10$$

To determine whether $F = 10$ is significant at the 5- or 1-percent levels, refer to Table 31 and note where the df of the between groups column (2) runs down and intersects the row marking the df of the within groups (12). It can be seen that $F = 3.88$ for 5 percent and $F = 6.93$ for 1 percent significance. Thus, since the value of 10 is larger than the table value of 6.93, one may conclude that the observed value is significant. The null hypothesis to the effect that one obtained random samples from a common (normal) population is rejected. Hence, the means of the samples differ significantly, and one is free to attempt to explain what influence, if any, the disposal of dredged material has had on the observed differences.

Analysis of variance need not be calculated directly, as many software programs for microcomputers include this routine (e.g., Wilkinson 1987). When the results of the ANOVA are significant, a number of approaches can be used to describe which means differ significantly. Usually these take the form of multiple range tests where the means are ranked from high to low, with those that are essentially the same being underlined by groups. Such an approach is purely descriptive, and can be improved by using tests such as orthogonal contrasts of the means.

Orthogonal contrasts essentially enable the researcher to state, a priori, certain distributional hypotheses about the collections. Above we have used the example of tests involving a disposal site and upcurrent and downcurrent sites or stations. Analyses of variance were conducted and indicated significant differences among station means. With orthogonal contrasts we are allowed one contrast per each degree of freedom for between group sources of variance. Hypotheses might be

- a. There are no significant differences in the abundance of Bivalve sp.1 between the upcurrent site (control) and the disposal and downcurrent sites.
- b. There are no significant differences in the abundance of Bivalve sp. 1 between the disposal and downcurrent sites.

The first step in the contrast is to assign coefficients in order to weight the sums for each station:

	<u>Station</u>			
	<u>Control</u>	<u>Disposal</u>	<u>Downstream</u>	<u>Sum</u>
Control versus treatment	+2	-1	-1	0
Disposal versus downcurrent	<u>0</u>	<u>+1</u>	<u>-1</u>	<u>0</u>
Sum	+2	0	-2	0

For the contrasts to be orthogonal, the sums of the products of the coefficients for each station must be 0 (e.g. $(+2)(0) + (-1)(+1) + (-1)(-1) = 0$). The sum of squares for each contrast is next calculated:

$$\text{Control versus treatment } \frac{[+2(50) - 1(20) - 1(35)]^2}{5(6)} = 67.50$$

=

$$\text{Disposal versus downcurrent } \frac{(+20 - 35)^2}{5(2)} = 22.50$$

where the numerators are the application of the coefficients to the sums for each station, the denominator is the product of the number of replicates (5), and the second factor is the sum of the coefficients squared and added.

Note that the total of the two sums of squares must add to the between group SS. Since each contrast corresponds to 1 df, the mean squares (MS) for each contrast are 67.50 and 22.50. The F value for each contrast is determined by dividing each contrast MS by the within group MS, in this case, $67.50/4.5 = 15.0$, and $22.50/4.5 = 5.0$, respectively. At 1 and 12 df, both are significant at the 5 percent level and the first contrast (control site versus treatment) is significant at the 1-percent level (Table 31). From this analysis we can conclude that abundance in the upstream or control area was significantly higher than in the area affected by the disposal site, and that abundance in the disposal site area was significantly lower than downstream of this site.

Presentation of Population Data from Macroepifauna

Effective numerical sampling of the macroepifauna is more difficult to achieve than it is for the macroinfauna. Nevertheless, many of the marine organisms of commercial value fall in this category, including bottom-feeding (demersal) fishes and shellfish. The macroepifauna may be defined as those organisms that either live upon the sediment bed or feed from the bottom and that are over (usually well over) 0.5 mm in length. Most of the species involved are quite mobile. In addition to demersal fishes, such as the flounder and other flatfishes, common components of the macroepifauna are crabs, shrimps, lobsters, and gastropod molluscs (snails). The obvious commercial value of species that belong in the macroepifauna should not minimize the importance of the macroinfauna in the mind of the reader. This study is dealing with an ecosystem, and the macroinfauna and even the smaller meiofauna (to be discussed next) are the principal source of food of the macroepifauna.

The question that must be answered now is what uses can be made of population data derived from sampling of the macroepifauna. It is not as easy to obtain a quantitative sample of this group as it is of the infaunal types. As noted in Part VII, the authors recommend use of the beam trawl, which has a more or less fixed aperture of, say, 3 m. At shallow sites it is relatively easy to observe, by the action of the towing wire and accumulator, when the trawl has engaged the bottom and when it has left the bottom during retrieval. Knowing the time on bottom and the speed of the ship across the bottom, the distance sampled times the gape of the trawl will give the area sampled. Most towing will be done

at a speed of near 1.5 knots (1.5 nautical miles or 2,780 m per hour); thus, a 10-min tow can be expected to traverse about 460 m and, multiplying by the 3-m gape, to sample 1,400 m². Obviously these are at best only gross estimates. Some investigators may simply prefer to work with units of effort and normalize the collection data in terms of the number of organisms taken in 10 min. Ordinarily, three trawl stations are planned for a dredged material site and its contiguous area: one in the site, one downstream, and one upstream. Duplicate trawl hauls are made at each station.

In the macroepifaunal samples, the number of species is not so great that all species cannot be identified; however, it may well be that population data need to be taken only for the principal or predominant species in each taxonomic group, such as fishes, crabs, shrimps, gastropods, etc. These data, then, can be handled statistically in the same way as those obtained for the macroinfauna.

Important comparisons can be made between the hauls inside the site and those outside, individually and jointly. Macroepifaunal data of the population type will be useful primarily to characterize the site and its adjacent areas, but there may well be some monitoring value in the data collected for predominant species. Actually, community parameters may yield some data of greater value to monitoring, as will be discussed shortly.

Some of the macroepifaunal species may be appropriate for the analysis of various pollutants, such as trace metals, aromatic petroleum hydrocarbons, PCBs, and organochlorine pesticides. One frequently encounters strongly held opinions that these larger and more mobile species are unsuitable for such analyses for the reason that if they do wander about and if their tissues have low values of pollutants, it could be that they happened to move into the disposal site just prior to capture and thus could not have acquired a body burden of the toxicant. No one can deny the truth of this possibility for some species. However, there is some evidence that lobsters (*Homarus*) which live near the coast do not move about over a few nautical miles. For example, Templeman (1935) found the average straight-line distance between points of release and recapture in the Gulf of St. Lawrence to be less than 4.5 nautical miles even after being at large for 12 months. Cooper (1970) tagged and liberated 1,776 lobsters off Monhegan Island, MA, and later recovered 99 percent within 2 nautical miles of the release point. Apparently this is not true of offshore populations, which undergo extensive seasonal migrations. On the other hand, there is little good evidence that some of the *Cancer* crabs move about on a regular basis. In fact, after maturing they may well stay put for considerable periods. Also, some of the demersal fishes actually live in shallow burrows or depressions in the bottom to which they return after feeding forays. Therefore, it is unnecessary to rule out all epifaunal species for pollutant analyses, but regionally experienced marine biologists both in agencies and universities should be called upon to make the species selection.

Presentation of Population Data from Meiofauna - Optional

The meiofauna are small, ranging in size from 0.5 down to 0.062 mm, which means that the smallest are equivalent to a 4-phi sediment grain (on the boundary between fine sand and coarse silt), and the largest are on the boundary between medium sand and coarse sand. What they lack in size they make up for by the very large size of their populations and in some places by substantial biomass (weight of living tissue). Because the meiofauna may have populations around a million per square meter, one need only take samples of 10-cm², 5-m-deep areas. In some areas the biomass of the meiofauna is

equivalent to that of the macroinfauna, depth for depth, in the sediment. Several other characteristics heighten their importance to marine ecosystems and to monitoring and impact evaluation studies. In the first place, many live an interstitial life where they are exposed to pore water. Hence, they are very likely to pick up any dissolved metals and other pollutants. It is now suspected that organisms such as shrimp and bottom-feeding fish depend upon the meiofauna for food and thus enter the food chain to man (Pequegnat and Venn 1979).

Since, in most marine sediments, the nematode worms account for 90 percent or more of the meiofaunal populations and the harpacticoid copepod crustaceans are second in abundance, it is recommended that counts be made only of these two groups. Because the meiofauna is subsampled from a box core, fairly reliable quantification can be achieved. Two samples covering 10 cm^2 by 5 cm deep are removed from each box core. Processing the sample for microscopic examination (25 percent) is not very difficult.

It is recommended that the ratio of population size between harpacticoids:nematodes be derived for each station (Parker 1975; Pequegnat and Sikora 1977, 1978, 1979). This can be nicely correlated with sediment parameters because all major factors are sampled from each meiofaunal box core. As might be expected, some aspects of the meiofauna respond dramatically to shifts in the sediment; this is especially true of the nematodes, which display increasingly large populations as sand percentages approach and exceed 60 percent. Since harpacticoid populations respond less to sediment changes than to levels of biologically available organic matter, shifts in the nematode:harpacticoid ratio at individual stations reflect the nature of the environmental change. It is important that the ratio be calculated for changes at individual stations only.

It is recommended that the harpacticoid:nematode ratio be utilized as a definitive parameter for tagging the transport of sediment into the extended impact zone and beyond. It is advisable that sufficient sediment samples be taken per station (minimum of three) to permit statistical evaluation of the data.

Presentation of Community Parameters

Whereas up to this point interest has been primarily in the numerical abundance or population of certain given species, the concern here is with the species composition of the community of organisms found at sampling stations. Although the community should be thought of as encompassing organisms of all ecological types (macroinfauna, macroepifauna, meiofauna, etc.), ordinarily only the data derived by one sampling gear are treated at any one time. Later, if one wishes, all such data can be combined.

It is not feasible to collect all species of a community, especially with a single type of collecting gear. At best one has only an estimate. The reason for this is simply that neither the time nor the resources are available to produce a true representation of the community. A moment's reflection will reveal that if a beam trawl is being used, individuals are added at a more or less constant arithmetic rate, whereas species are being collected at a decreasing logarithmic rate (Figure 35). Note that at first probabilities are high that each added individual will be a "new" species, but as sampling goes on this rate drops rapidly. A rule of thumb as to the completeness of sampling states that if the sample collected at a station contains any species represented by a single individual, there are yet uncollected species in the same size category.

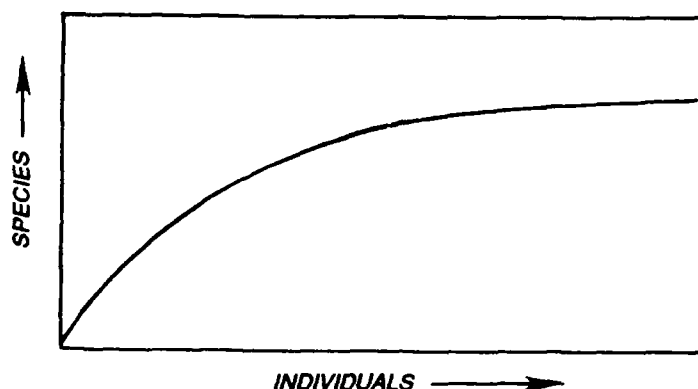


Figure 35. Graph showing the dependence of adequate representation of the total species at a station upon the number of individuals collected. Note the relationship of this parameter to the lognormal curve discussed below

We suggest three steps in the presentation of community parameters. First, one should evaluate the fit of the data to a lognormal distribution. This will enable an assessment of the effectiveness of the sampling effort and is of interest per se. The second step is to calculate three measures of species diversity--species richness, species diversity, and evenness. Lastly, a measure of community similarity should be conducted.

Lognormal population distribution

In order to judge the effectiveness of a sampling effort in obtaining a reliable estimate of the actual number of species at a disposal site, one should utilize the lognormal distribution to assess the situation. The curve in Figure 35 suggests that additional sampling can be expected to yield more species, but it is difficult to estimate where one's sampling effort is located on the curve. For this purpose, a plot of the lognormal distribution is informative. One first converts the species abundance patterns to a geometric scale, e.g., \log_2 where the scale units would be 1, 2 to 3, 4 to 7, 8 to 15, etc., and then sums the number of species within each scale (= octave). The octaves are plotted from low to high on the abscissa, and the number of species in each octave (not in logs) constitutes the ordinate (Figure 36). In actual practice (in the real world), the lognormal distribution is truncated at the point where species are represented by a single individual (Figure 37). The degree of truncation is proportional to the amount of the universe of species sampled. The area under the extrapolated full lognormal curve gives an estimate of the total number of species N in the theoretical species universe. The area under the truncated sample curve represents the number of species n in the sample. Therefore, the ratio n/N gives the fraction of the species universe in the sample.

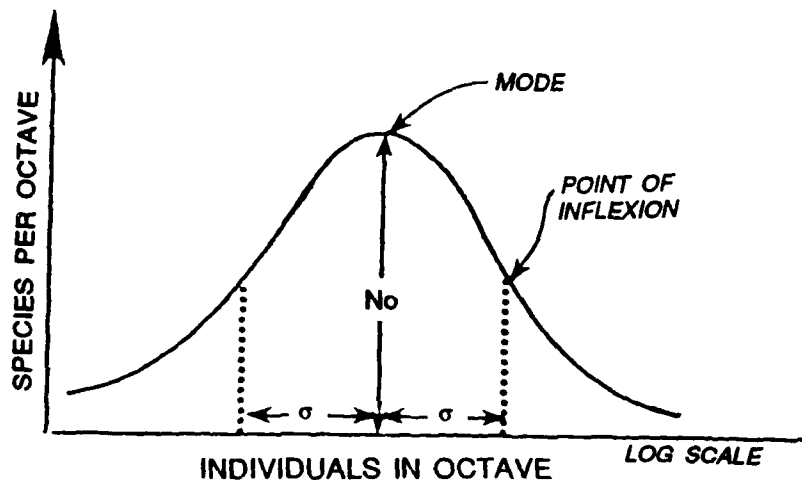


Figure 36. Hypothetical lognormal curve showing the numbers of individuals (logs) in species. No = the modal class, and sigma is one standard deviation on each side of the mode. In biological field sampling such a universe is seldom or never obtained (see Figure 37)

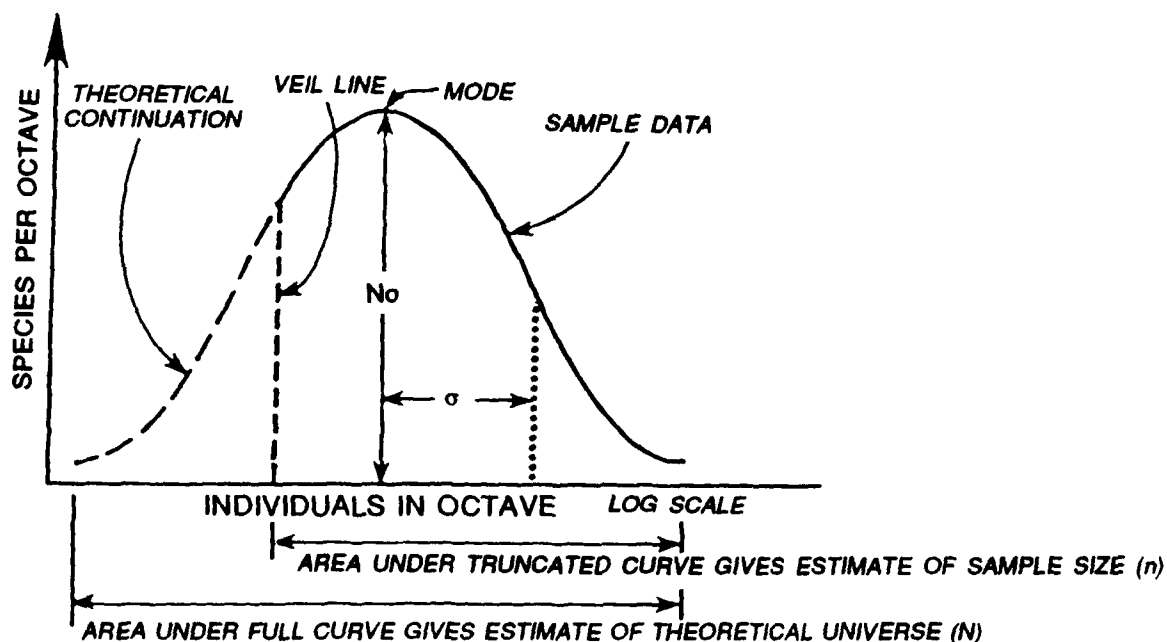


Figure 37. Lognormal curve obtained from field sampling. Since the veil line is to the left of the mode, it is possible to move the curve to the right and thereby estimate the total number of species from which the actual sample was taken

From the sample curve, the theoretical population universe can be estimated as

$$N = \sqrt{2\pi\sigma N_0}$$

where

N = total number of species

σ = logarithmic standard deviation, i.e., distance from the mode to the point of inflexion of the curve

N_0 = number of species in modal octave

If the mode falls behind the veil line, a larger sample is required to place the veil line two octaves to the left of the modal octave where the sample lognormal curve is thought to be a fairly accurate representation of the truncated universe curve. Since doubling the size of the sample doubles the number of individuals of the more common species in the sample, this is equivalent to moving every species one octave to the right and withdrawing another octave from under the veil. Thus, given the position of the mode, one can estimate how many times the sample size needs to be doubled before the mode falls two octaves to the right of the veil line. For example, if one beam trawl tow gives a truncated curve with the veil line one octave to the left of the modal octave, then a second tow should place the veil line two octaves to the left. However, it would take 2^2 tows to move the veil line two octaves to the left (Williams 1953).

Species diversity

A biological community has an attribute called species diversity, and many different ways of measuring this concept have been suggested. The first assumption for measuring community diversity is that the subject matter is well defined. Measurement of diversity requires a clear taxonomic classification of the subject matter. In most cases, ecologists worry about species diversity, but there is no reason why **generic** diversity or even **sub-specific** diversity could not be analyzed (Krebs 1989). Above we touched on how much of the community should be included in the analysis. Most researchers choose one segment--e.g., fish species diversity, macroinfauna species diversity, polychaete species diversity, etc. There are no rules available to guide one in what to include in a "community diversity" analysis.

The oldest and simplest concept of species diversity is **species richness**, the number of species in the community. Above we have given one approach for estimating this variable. However, we have also noted that communities, or even particular segments of the community, will seldom ever be completely sampled. Further, another problem that frequently arises in comparing community samples is that they are more often than not based upon different sample sizes. One way to overcome this problem is to standardize all samples to a common size. Rarefaction is a statistical method for accomplishing this goal and provides a comparable set of species richness data.

Hurlbert's modification (1971) of the rarefaction method (Sanders 1968) can be used to predict the number of species in a random sample without replacement, given a population N :

$$E [S_m | N] = \sum_{i=1}^k 1 - \frac{(N_m - N_i)}{\binom{N}{m}}$$

in which N_i is the finite population of species i ; N is (N_1, N_2, \dots, N_k) , a vector representing the entire finite population; and S_m is the random variable denoting the number of species in a sample of size m (Smith and Grassle 1977). This, N is the total number of individuals in the finite population:

$$\sum_{i=1}^k N_i$$

This analysis yields a family of curves showing the relative number of species expected for a given sample size at the respective stations. It provides a diversity measure independent of sample size effects.

While appearing a formidable calculation, a worked example can be found in Krebs (1989), who also provides the computer program RAREFACT in his Appendix 10.1 that will do the calculations. Likewise, Simberloff (1978) provides a discussion of the calculations and provides the computer program Rarefaction Program SIM for doing the calculations.

As used in recent years, the term **species diversity** usually denotes indices that attempt to measure **community heterogeneity**. For example, if a community has 10 equally abundant species, should it have the same diversity as another community with 10 species of which one or two make up 99 percent of the total individuals? No is the answer of many researchers. This has led to a number of indices which combine the two separate ideas of **richness** and **evenness** or **equitability**. (See Krebs 1989 and Magurran 1988 for reviews.)

The most popular measures of species diversity are based on information theory developed by communication engineers interested in predicting correctly the name of the next letter of a message. Ecologically, the question is how difficult would it be to correctly predict the species of the next individual collected? A measure of this uncertainty can be obtained using the Shannon-Wiener (not Shannon-Weaver, Krebs 1989) function:

$$H' = - \sum_{i=1}^s \pi \log_e \pi$$

where

H' = information content of the sample (nits/individual)
index of species diversity

s = number of species

π = proportion of total sample belonging to the i^{th} species.

Since information content is a measure of the amount of uncertainty, the larger the value the greater the uncertainty in correctly predicting the species represented by the next individual collected.

If the information content unit (nits/individual) is troubling, the Shannon-Wiener index can be expressed in a different form, following MacArthur (1965):

$$N_1 = e^{H'}$$

where

N_1 = number of equally common species that would produce the same diversity as H'

$e = 2.71828$

H' = Shannon-Wiener function

Peet (1974) recommends the use of N_1 as the best heterogeneity measure of the ones that place emphasis on rare species.

The evenness component of the Shannon index is easily calculated

$$J' = \frac{H'}{H' \text{ max}}$$

where

J' = evenness measure (range 0-1)

H' = diversity index

$H' \text{ max}$ = maximum value of $H' = \log_e S$ (the number of species)

While H' is a simple calculation, Krebs (1989) provides computer program DIVERS in Appendix 10.5 that will calculate the Shannon-Wiener function and evenness values for species abundance data.

Strictly speaking, the Shannon-Wiener measure of information content and its associated evenness value should be used only on random samples drawn from large communities in which the total number of species is known (Pielou 1966). This is seldom if ever the case. Even though many workers have used H' measure of species diversity, the information theory approach has been heavily criticized by some, with Hurlbert (1971) going as far as calling it a "non-concept." Diversity indices can be valuable for detecting community change, but are only one means to an end. That end is that environmental managers should be able to ask appropriate questions and formulate the testable hypothesis that will help them understand and sensibly manage the natural world.

The basic assumption underlying the desire on the part of some to calculate the species diversity index in a site monitoring or designation program is that it will reveal a great deal about the structure of a community. This is clearly a debatable issue because the index alone does not depend upon what species are present, i.e., it does not deal with the species composition of the community. In our view, **species richness** determinations together with **species composition** are more important to site characterization, impact evaluation, and monitoring in general than are diversity indices per se.

The reason that species composition as well as richness are important relates to energy flow and the fact that energy enters the lower feeding levels and moves through the community by alternate pathways and feedbacks until it reaches the top carnivore. When

stresses such as excess heat or toxicants are applied to the species of the community, extra energy must be expended to ameliorate the stress. Those species that cannot meet the demands of stress, that is, who have narrow environmental tolerance, will drop out, thereby leaving a smaller number of species or subjecting the community to invasion by (up to then) alien species. Pollution applies stresses; hence, species diversity can be expected to go down or species replacement can occur, or both.

Index of similarity

It will be valuable to search for faunal homogeneity among collecting stations by classifying the different sample stations in a simplifying pattern of groups of stations. Both time and space parameters may account for observed differences in community structure of various stations. The changing effect of time may appear as a result of natural seasonal influences, which must be separated from time-dependent stresses of environmental change that produce chronic responses. Since the influence of these stresses, if related to dredged material disposal, will differ depending on the location of the station relative to the point of disposal, spatial considerations become important in accounting for change.

The following method of classifying stations depends upon the fact that stations within groups are more closely related to one another than to those belonging to different groups. The basis for establishing the closeness of relationship will be the species list derived from each station. Thus, the index of similarity overcomes one of the disadvantages of the species diversity index to the effect that it is simply based on the number of species rather than on what they are (Mountford 1962).

Stepwise Calculation of the Index of Similarity

Step 1

To arrange stations into groups, construct an index that gives numerical value to the similarity between two stations in accordance with the simplified form below. The index of similarity Z is calculated as

$$Z = \frac{2c}{2ef - (e + f)c}$$

where

c = number of species common to both station lists

e = number of species in first station list

f = number of species in second station list

Suppose that one is attempting to classify the five stations A, B, C, D, and E and that one has calculated the following matrix of the indices of similarity:

	A	B	C	D	E
A	--	0.15	0.23	0.19	0.21
B			0.27	0.29	0.23
C				0.27	0.24
D					0.14
E					--

Step 2

From the above table, select the **highest value**, which in this case is 0.29. The pair corresponding to this value, B and D, is combined to form a single group, BD. The indices of similarity between each of A, C, and E and the group BD are then evaluated.

Step 3

The index between A and the group BD is

$$Z(BD;A) = \frac{Z(AB) + Z(AD)}{2} = \frac{0.15 + 0.19}{2} = 0.17$$

In this way one obtains the reduced matrix

	A	BD	C	E
A		0.17	0.23	0.21
BD			0.27	0.19
C				0.24

The highest value is 0.27 between C and BD; therefore, BD and C are combined.

Step 4

The indices of similarity between A and E and this new grouping are

$$Z(\text{BCD};\text{A}) = \frac{Z(\text{AB}) + Z(\text{AC}) + Z(\text{AD})}{3} = \frac{0.15 + 0.23 + 0.19}{3} = 0.19$$

and

$$Z(\text{BCD};\text{E}) = \frac{Z(\text{EB}) + Z(\text{EC}) + Z(\text{ED})}{3} = \frac{0.23 + 0.24 + 0.14}{3} = 0.20$$

The reduced matrix is

	A	BCD	E
A	--	0.19	0.21
BCD		--	0.20

The highest value is between A and E; hence, they are combined.

Step 5

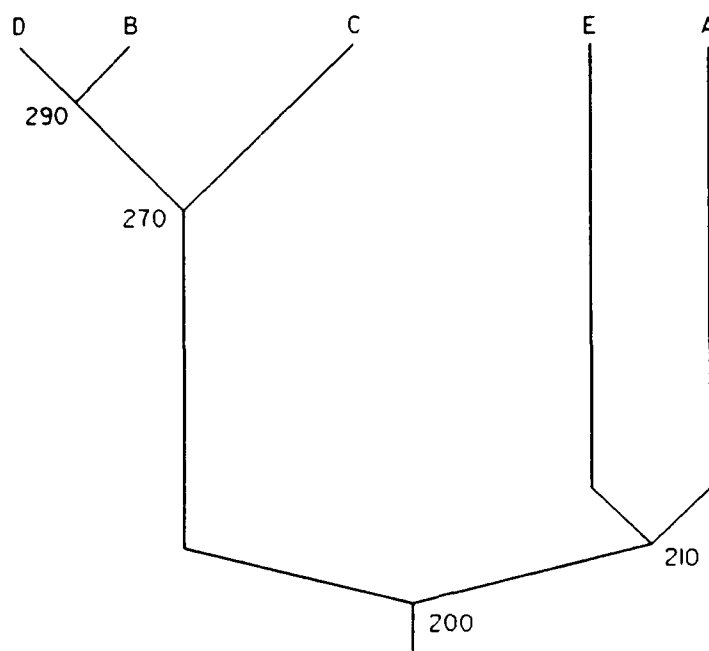
The index of similarity between AE and BCD is:

$$Z(\text{AE};\text{BCD}) = \frac{Z(\text{AB}) + Z(\text{AC}) + Z(\text{EB}) + Z(\text{EC}) + Z(\text{ED})}{6} = \frac{0.15 + 0.23 + 0.19 + 0.23 + 0.24 + 0.14}{6} = 0.20$$

	A	B	C	D	E
A	--	0.15	0.23	0.19	0.21
B		--	0.27	0.29	0.23
C			--	0.27	0.24
D				--	0.14
E					--

Step 6

At this point one is ready to display the clustering of stations as a branching graph called a dendrogram. The levels of branching are determined by the values of the indices of similarity ($\times 10^3$).



Note that BCD make one major branch and AE make the other. Within the group BCD, the largest index of similarity is between B and D, hence; one is shown branching off of the other.

This might reflect an actual set of five sampling stations in and adjacent to a dredged material disposal site, where stations E and A are within the site, C is in the impact zone, and D and B are upcurrent stations. It is thought that this station or site clustering technique may assist in describing quantitative differences in faunal homogeneity between natural and disturbed benthic faunal communities or assemblages.

Cluster Analyses by Computer

The above example of determining community similarity and presenting the results by means of a cluster diagram is highly simplified--a precomputer age example. If classification of sites based upon similarity in community attributes is considered an important step in achieving the goals of the program, one should consult a comprehensive book on cluster analyses (e.g., Romesburg 1984).

Several key decisions must be made, including (a) what type of similarity measure to use, (b) whether the data should be standardized or transformed, and (c) what clustering algorithm should be used to construct the dendrogram. Each of these decisions can greatly affect the outcome of the analysis. Each of these decisions involves a subjective judgment. Given a set of data there is no one objective "correct" cluster analysis. Krebs (1989) states that the central paradox of cluster analysis is that "each method is exact and objective once the subjective decisions have been made about the similarity index and data standardization."

One of the most frequently used clustering strategies is called UPGMA (unweighted pair-group method using arithmetic averages, Sneath and Sokal 1973). Romesburg (1984)

evaluated many possible methods and concluded that UPGMA is appropriate for most types of cluster applications. Krebs (1989) provides a worked example of this method in his Chapter 9 and notes that Davies (1971) provides a simple computer program for clustering and that Romesburg (1984) describes a more complex series of programs. Also, many of the commercially available software packages such as SYSTAT, Inc., include cluster programs.

Uses of Classification Analyses in Practice

Biological classifications based upon cluster analysis can be directly compared to the environmental classifications based on approaches such as PCA (see Figure 34) to determine those environmental variables which appear most important in influencing community structure. For example, the output of the biological cluster analysis corresponding to the same array of stations defined by PCA of physical variables (see Figure 34) is shown in Figure 38. Note that the authors interpreted the results to indicate four groups of stations and assigned each a unique symbol. When these symbols were superimposed on the proper station location on Figure 34, the two classifications showed good agreement, even to the subgroup levels for the most part (Figure 39). The only notable exception was that Station C2 grouped with middepth stations in the PCA analyses and with the "shallow" group of stations in the biological analysis. While the station classifications were characterized by depth group for discussion purposes, neither depth nor hydrostatic pressure was used directly in the analyses. Environmental variables that were indicated to be of importance in the biological classification were, thus, bottom temperature and salinity, hydrocarbon levels, and sediment characteristics.

Classification analyses can be particularly important for monitoring programs. They can yield results suggesting what environmental variables appear most important in controlling community composition and thus yield a reduced list of attributes to monitor. Biological classifications compared over time can show how the community may be responding to changes in environmental variables should such changes occur. Of importance, the most likely factors accounting for the biological changes can be identified, and these may or may not be factors associated with dredged material disposal.

APPLICATION OF CRITERIA FOR DATA INTERPRETATION

Ecosystem: Environmental Unit of Concern

Even in its simplest form the ecosystem includes all of the biological and nonbiological components of the environment, such as water, sediments, temperature, salinity, etc., and their interactions. In each environment the prevailing condition of the system has been produced by dynamic interaction among its physical and biological components, processes, and outside forces. If any one of these biological components is changed, say, by addition of a significant stress, a new balance is reached in the system. Each ecosystem possesses those species and biotal communities that are adapted to the specific environment and are therefore successful in that environment. Pollutants will modify the specific environment, adding stresses, and may eliminate susceptible species. In some instances, unwanted species may be nurtured. If the stresses are severe, the system will become less productive and of less value to man. If stresses are both severe and persistent, disruption of the entire ecosystem may occur. Dredged material does stress the marine environment,

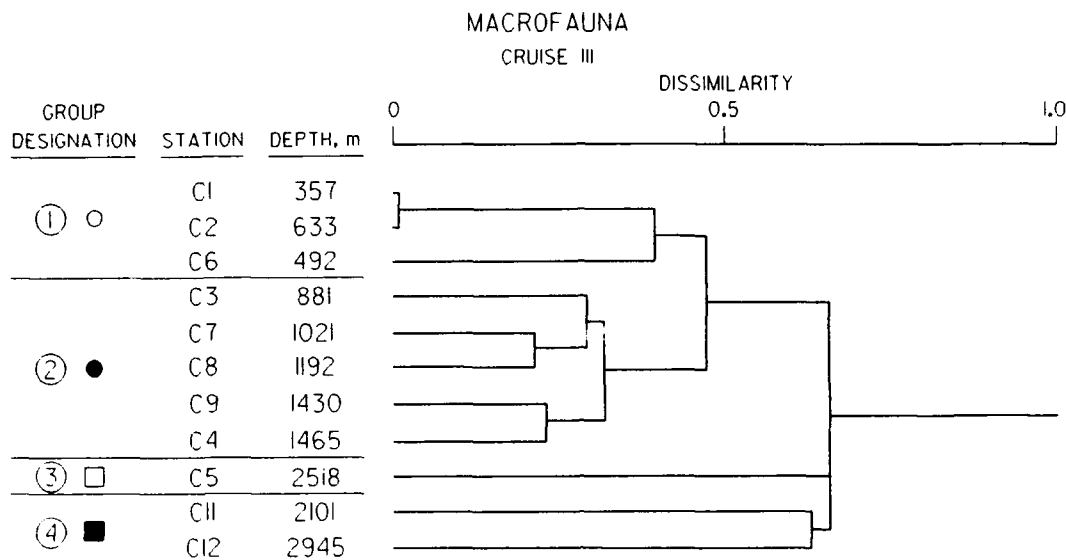


Figure 38. Results of cluster analysis for central transect stations sampled on Cruise III, fall 1984

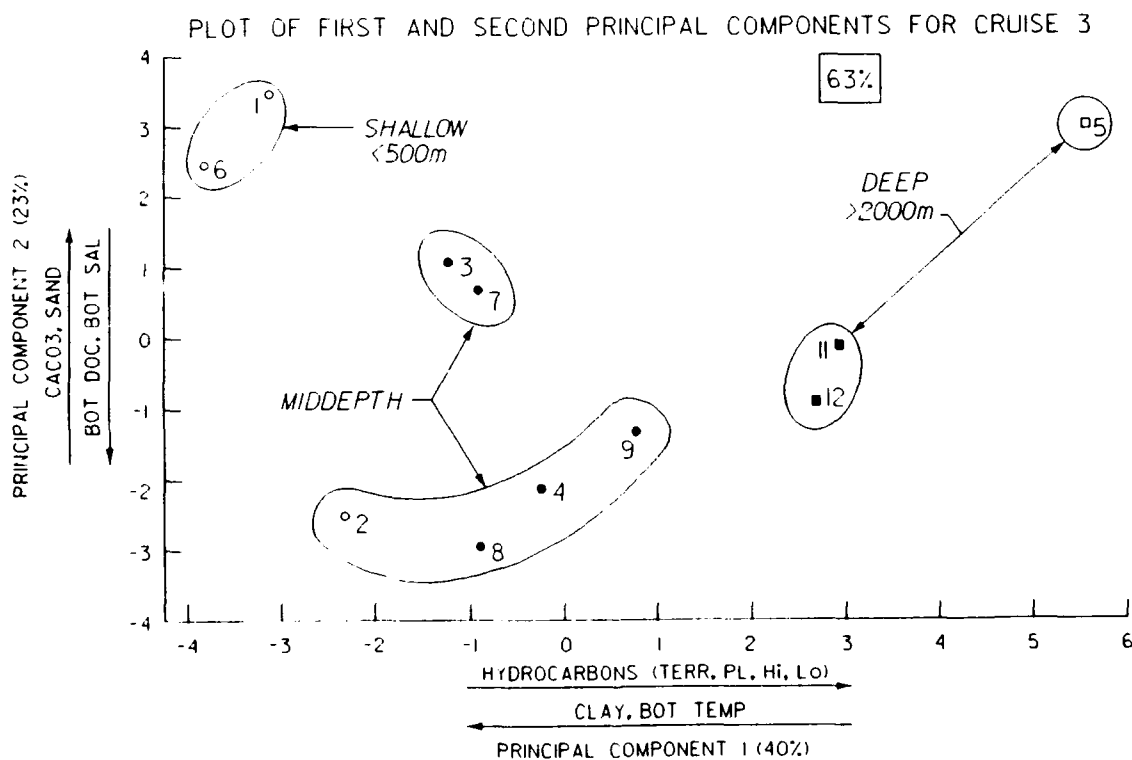


Figure 39. Results of biological cluster analysis for central transect stations sampled on Cruise III superimposed by overlaying group designation symbol on the results of the corresponding PCA analysis

but in general few of the stresses are severe and persistent, except perhaps at a point of repeated disposal. The objective of the following discussion is to provide guidelines for stress evaluation.

Ecosystem Impacts of Dredged Material

Examples of stresses that dredged material may have on the system are to:

- a. Increase turbidity for short periods in surface waters and for longer periods in deeper layers, thereby reducing inputs of solar energy, which may result in some reduction of primary production by phytoplankton and fixed plants; this may also injure respiratory surfaces of some animals and interfere with olfaction.
- b. Increase the concentrations of some nutrients and of organic matter, resulting in population increases in some species. Ordinarily these species will be undesirable, and their population explosion will itself stress other species.
- c. Reduce the availability of some nutrients by increasing sedimentation with accompanying sorption.
- d. Eliminate some species by substrate changes, thereby increasing chances of reduction of community diversity.
- e. Facilitate bioconcentration or bioaccumulation of toxic materials present in low levels in dredged material.
- f. Overthrow the biomass balance of the system by either reducing abundant species or by removing carnivores, thereby permitting prey species populations to expand rapidly
- g. Reduce species diversity.

Need for Benchmark Data

The importance of establishing a reliable set of benchmark or baseline data on the benthic fauna in the initial ocean surveys is demonstrated by the species diversity parameter in its simplest form, namely, the number of species in the community. When stresses are applied to the organisms of the community, energy will be spent to counter the stress. The early effects of this expenditure will be to overwhelm and remove species with narrow tolerances. Then, when the point is reached involving survival of the whole community, biomass falls off rapidly. Thus, the impacts of even low levels of pollution upon already stressed communities will result in an apparent exaggerated response.

Bioconcentration, Bioaccumulation, and Stress

Larger accumulations of contaminants in the tissues of the constituent species of a community affected by disposal of dredged material than in individuals from the control site are a signal that stresses may exist. This uptake may result in either acute or chronic responses. The path of entrance of the contaminants bears upon the selection of some aspects of the survey. A study by Macek, Petrocelli, and Sleight (1979) indicates that the principal route for the uptake of many contaminants by finfish and shellfish is directly from the water through the gills and other epithelial surfaces, such as in the gut, rather

than through dietary sources. The direct process is called **bioconcentration**, as distinct from **bioaccumulation** which includes both the dietary and direct processes.

The principal contaminants that may be carried by dredged material to the marine environment are heavy metals, Aroclors (PCBs), high molecular weight hydrocarbons, and chlorinated hydrocarbons such as aldrin, dieldrin, endrin, kepone, and DDT. When concentrations of these compounds reach high enough levels in the body, death will ensue. The rate at which this uptake occurs depends in part upon the species of animal involved and the concentration of the compound in the environment. More frequently than not, the environmental manager has more data on the concentrations of contaminants in the physical environment than in the biota. For that reason, the discussion to follow will deal with environmental concentrations rather than biotal. This is all the more appropriate in light of recent evidence regarding the occurrence of biomagnification.

Trophic level biomagnification, the process by which tissue concentrations of bioaccumulated chemical residues increase as these materials pass up a food chain, is not as common an occurrence as was once thought from the original findings for DDT. Macek, Petrocelli, and Sleight (1979) state that one can screen compounds for their potential of causing significant biomagnification by determining the rate at which the organism can rid itself of body burdens (called depuration) when placed in uncontaminated water. DDT is used as the calibrating compound for tests to show that fish require an average of about 140 days to eliminate 50 percent of their body burden of this compound. On the other hand, only from 14 to 42 days are required for depuration of PCBs and kepone. Whereas DDT concentrations are magnified by food chain transfers, it appears that PCBs, kepone, and other easily excreted compounds are not. Actually, then, the environmental manager should concentrate attention on obtaining as much information as possible on the concentration of contaminants in the ambient waters and, to a lesser extent, in the sediments. However, to assess the development of chronic effects from the accumulation of initially low levels of contaminants, the assay of appropriate metabolic enzymes may be the method of choice.

PART IX: MONITORING OF MARINE DREDGED MATERIAL DISPOSAL SITES

ELEMENTS OF A SITE MANAGEMENT PLAN

Recent years have ushered in a trend of increasing interest in and concern with the management of ocean sites for the relocation of dredged material. Management plans are generally site-specific in that they are based on (a) types and quantities of dredged material to be disposed from imminent or anticipated projects, (b) specific characteristics of the site, including the types and locations of resources and amenities, and (c) issues of local or regional concern. However, it may be advantageous to develop regional plans that will allocate resources more efficiently. It is always appropriate to fully coordinate with other regulatory or resource agencies. Such coordination is strongly encouraged as is a team approach to site management.

Whether site-specific or regional in scope, a management plan will have a certain minimum number of elements, which will be conditioned by site-specific considerations such as depth, frequency of disposal, etc. Critical functions of a management plan are to

- a. Establish and provide for management of the quantities and types of dredged material to be disposed at each site.
- b. Establish and regulate with justifiable cause the times, rates, and methods of disposal as needed, and when necessary, provide for application of appropriate special methods of disposal to prevent environmental degradation or, of equal importance, to create one or several beneficial uses of the dredged material (e.g., beach nourishment, subaqueous berms, fishing reefs, etc.).
- c. Call for development and continuance of an appropriate and effective monitoring program for each site.
- d. Provide for modifications of site usage, including abandonment, based upon experience in use of the site, especially that gained from monitoring and other postdisposal observations.

It is clear from the above considerations that monitoring efforts should be designed to serve as an integral part of the management strategy for the disposal site involved. Effective monitoring plans include provisions for analysis and integration of physical, chemical, and biological data into assessments that will aid the site manager in making decisions as to further site use.

More detailed guidance for managing dredged material disposal can be found in the CE Dredging Regulation, promulgated by the CE in 33 CFR Parts 209 and 335-338 on 26 April 1988. The official strategy has a framework composed of nine steps that require evaluation of all disposal alternatives based upon the results of appropriate testing. The first four of these steps are most germane to the present discussion in that they deal with testing and evaluation of disposal alternatives. These are as follows:

- a. Evaluate contamination potential.
- b. Consider potential disposal alternatives.

- c. Identify potential problems.
- d. Apply appropriate testing protocols.

Clearly the first three are predictive, calling for the crafting of null hypotheses. As we see in Figure 40, dredged material evaluation is a tiered approach in which testing stops at that level where adequate information is available to determine compliance with the criteria. A somewhat more elaborate flowchart developed by the CE's New England Division (part of the Disposal Area Monitoring System (DAMOS) Project) is presented in Figure 41. Notice the position of monitoring and the role that it plays in arriving at definitive management decisions.

Ordinarily when the site selection process is nearing completion, the underlying assumption is simply that the disposal of dredged material into the site will not result in unacceptable adverse effects outside of the site boundaries. This, of course, is what the 4-hr limit in the initial mixing process is directed toward (see the Ocean Dumping Regulations and Criteria). If we accept this proposition, then the principal purposes of monitoring are to ascertain whether unacceptable adverse effects are occurring or appear on the verge of occurring during and following the disposal process, and to verify that activities are in compliance with stipulations of environmental laws and regulations and of the site management plan. Other objectives would of course be to ensure that disposal operations are completed according to specifications and that the disposed sediments are acting as anticipated during and following disposal. The latter will permit planning for effective use of the site area.

UNACCEPTABLE ADVERSE EFFECTS

The phrase "unacceptable adverse effects" is found in the Ocean Dumping Regulations and Criteria. However, in that document the term seems to be defined in terms of effects upon individual entities, as ascertained primarily through bioassays of one type or another. This seems not to have met the complete satisfaction of many managers of the marine environment on either a national or international basis. Admittedly, we cannot propose a much more satisfactory approach, because the concept has a strong dependence upon the exercise of individual judgment. Still, there does now seem to be agreement, even internationally as seen in the London Dumping Convention, that effects (impacts) which are capable of changing an ecosystem as a whole are probably irreversible and as such are both adverse and unacceptable. Bold attempts are now being made to apply this interpretation to the entire North Sea. Unfortunately, the mechanisms that determine the limits of ecosystem resilience are largely unknown. Nevertheless, the formulation of large-scale physicochemical models and the ocean circulation studies (World Ocean Circulation Experiment) are giving us much more penetrating analyses than were available only a handful of years ago. More conservative managers have seized upon our deficiencies and call for prohibition of all usages of the ecosystem that they feel, perhaps intuitively, will impair it. On a technical basis this could entail no dumping whatsoever, but we are constrained to note that management of the marine environment must be guided by economic and political factors, as well as the technological.

Some managers are satisfied that there is a way based in law to judge whether or not an adverse impact is environmentally acceptable. No doubt, the accumulation of large amounts of dredged material will have inevitable but often transitory adverse physical

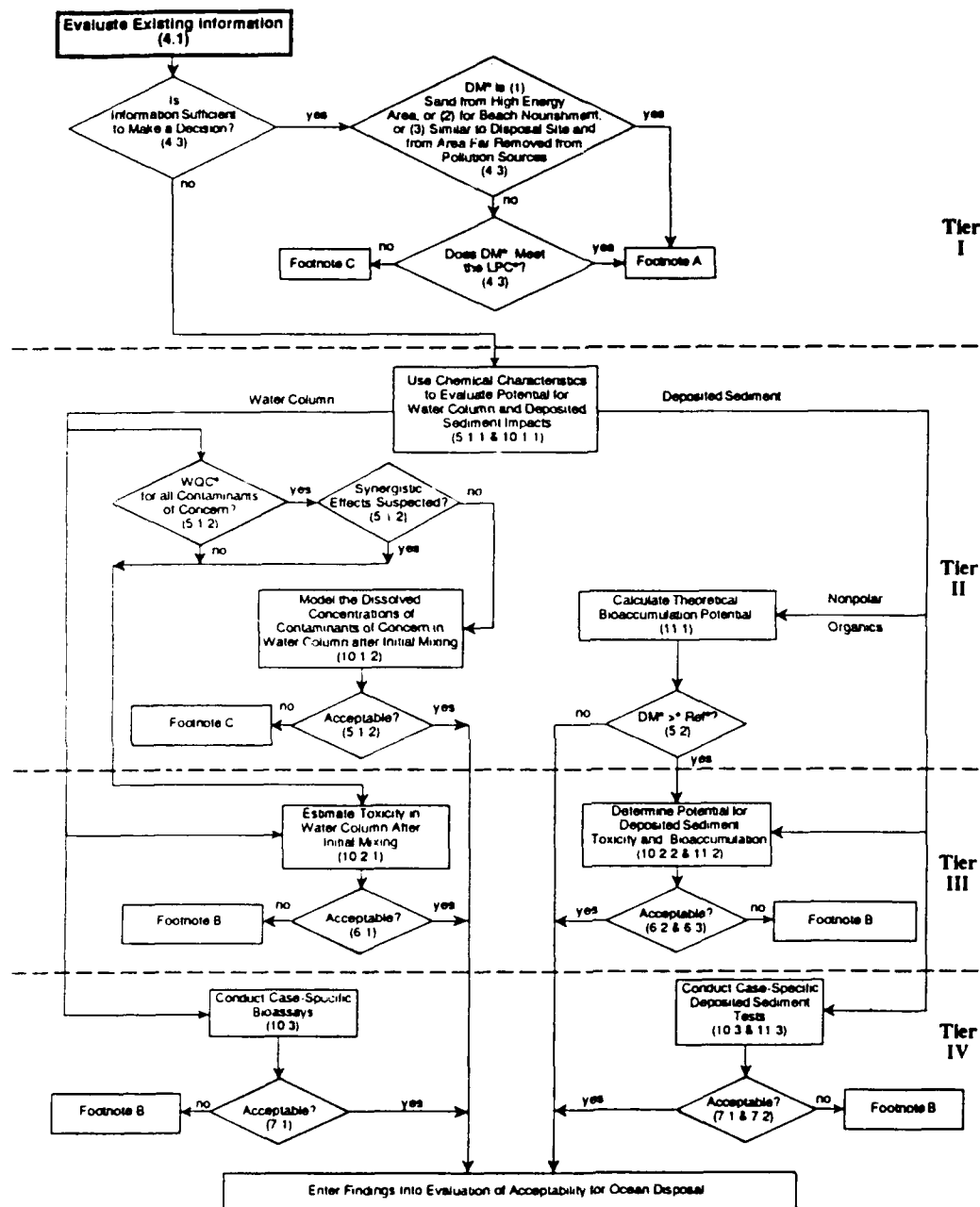


Figure 40. Overview of tiered approach to evaluating potential impacts of ocean disposal of dredged material. (References are to chapters, sections, and/or subsections of *Implementation Manual, USEPA/USACE 1990*)

effects on the biota within the reception areas of the site, but this does not justify assessing this to be unacceptable degradation. It may, however, be considered to be legally unacceptable if unacceptable adverse impacts of disposal are discovered outside the legal limits of the disposal site.

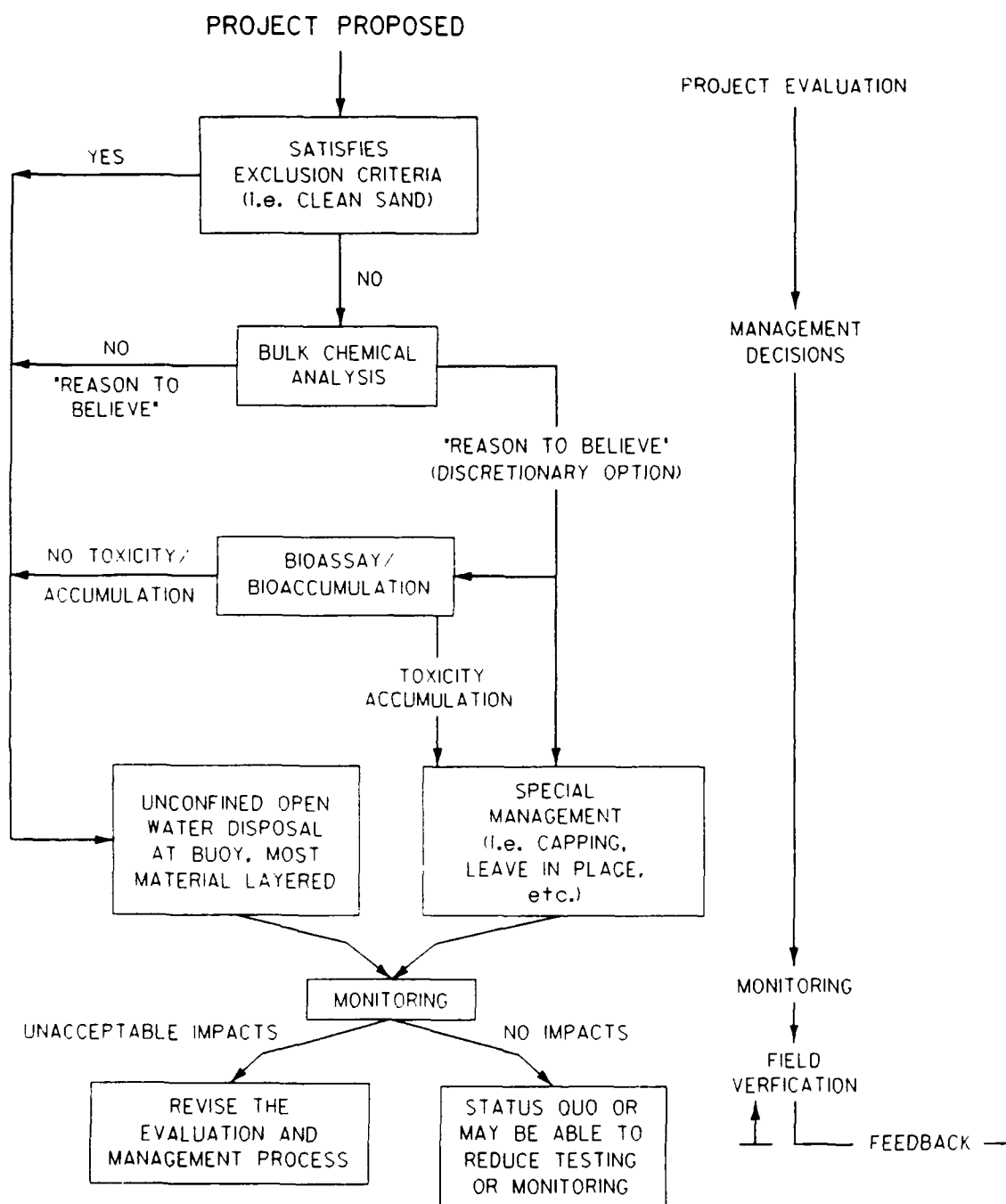


Figure 41. Draft tiered decision protocol for open-water disposal of dredged material (developed for DAMOS project, US Army Engineer Division, New England)

Other managers believe that there is a legal basis, both national and international, that supports the economic aspect of environmental protection. As Walker (1987) suggests, "contamination of the natural environment by human activity does not necessarily constitute pollution." This view is grounded in the concept of assimilative capacity, which

simply stated assumes that until the ecosystem gives a very negative response to a human input, it is not irreversibly damaged. It also assumes that there is a level or, better, a threshold which marks the imminence of the onset of damage. As we shall see, monitoring must understand and establish thresholds of damage that will warn the environmental manager that the management program may not be able to prevent widespread effects. However, those who favor the application of this methodology believe that the ocean can distribute and dilute materials to ambient levels within the limits of its assimilative capacity--a capacity that reduces costs of disposal without causing such signs of pollution as degradation of human health or of aquatic ecosystems and other legitimate uses of the ocean waters. Opponents of this approach counter that widespread dilution and dispersion can still cause stresses which if discovered to be damaging are already having widespread effects. This argument cites the contention that prevention is better than cure and in most cases is cheaper. Realistically, however, we must admit that the economic cost of the application of the prevention principle may be judged to be too high with the result that some governments fall back upon the best practicable environmental option.

THE ROLE OF PREDICTION IN MONITORING

During the process of selecting the location and size of an ocean disposal site, all relevant biological resources and amenities to be protected will have been located and studies will have been conducted of a sizable number of physical and chemical environmental factors. Now we are faced with predicting the processes, specific magnitudes, and areal extent of environmental change that would be necessary to bring about an impact upon these mapped resources. The real value of monitoring becomes clear at this point in that we can see that it focuses on detecting whether those physical or chemical processes that will bring about change in the resource are actually occurring. In most cases monitoring will not require working with as many parameters as were investigated in the designation process. But the monitoring program must nevertheless provide the site manager with sufficient unequivocal information to determine when the threshold of an adverse impact has been reached or is imminent. More specifically, a good program may not require one to measure more than a half dozen variables, but each must be clearly defined and critical quantitative thresholds established prior to sampling. Moreover, when properly carried out, the monitoring program must be able to predict the extent of adverse effects if the critical thresholds are exceeded.

PROSPECTIVE VERSUS RETROSPECTIVE MONITORING

It bears repeating to advise that monitoring should provide clearly interpretable information about whether a threshold of adverse condition has been reached or is likely so that decisions about continuing or modified site use can be made. This means that the production of critical data must be timely. A prospective monitoring program can do this because it consists of repeated observations that determine if site conditions conform to previously stated standards. It is more difficult for a retrospective program to do this because in it the types, magnitudes, and areal extent of adverse impacts are not defined until after sampling is under way and data are being interpreted (Moriarty 1983; La Salle, Nelson, and Clausner 1988; Fredette et al. 1990).

Relationship Between Predictions and Thresholds

In prospective programs, specific desirable and undesirable consequences of disposal are defined before sampling is begun. The manager is required to predict what resources at or near the disposal site are at risk and what magnitude and extent of impact could possibly result from disposal. The predictions should state how and at what thresholds physical and chemical changes will result in unacceptable biological responses. By so doing, the resources of interest are identified, specific thresholds of physicochemical or biological conditions that should not be exceeded are quantified, and potential impacts of disposal operations are predicted (Fredette et al. 1986).

Relationship Between Predictions, Thresholds, and Null Hypotheses

Identifying resources at risk, establishing thresholds at which changes in environmental conditions would be considered adverse, and predicting impacts are the most difficult parts of a prospective monitoring program. It is not sufficient for the site manager to note that he is concerned about the welfare of a particular species and as a result will monitor it during disposal (Fredette et al. 1986). Rather, it is required that the quantifiable changes in the resource be described and that the threshold at which the changes will become unacceptable be specified in advance. These requirements give purpose to the program and lead to the development of null hypotheses that must be tested statistically.

PRODUCING A MONITORING PROGRAM

There is no single pattern for the development of monitoring programs, but the modern approaches are taking on some of the qualities of a scientific experiment. Indeed, increasing use of the scientific method in setting up monitoring programs will not only produce better results but will also be more economical (Green 1984, Fredette et al. 1990). When the monitoring program is set up properly, one can craft a sampling program that will focus on detection of changes in specific conditions of importance rather than searching for any detectable change.

As our ideas about the nature of monitoring programs have grown clearer, we have begun to emphasize the desirability of reducing the time and effort devoted to the program without sacrificing its quality and thus value to the sponsor. Gradually we have learned the value of creating a multitiered monitoring program (Zeller and Wastler 1986) wherein each tier has its own predetermined environmental threshold and its own management option if the threshold should be violated. As we shall see, the more sophisticated programs, which are not necessarily the more expensive, demand a great deal of ecological knowledge about the resource species, but they compensate by producing data over a relatively short span of time. First, let us examine two flowcharts (Figures 42-43) that depict the steps that one might take in constructing a monitoring program for an ocean disposal site for dredged material.

Each step in Figure 42 represents a tier, ending with Step 5 where actions must be taken if the null hypothesis is rejected, as would be the case, if there is a significant difference between observed and predicted conditions in target parameters, or where no action would be required if the null hypothesis is verified.

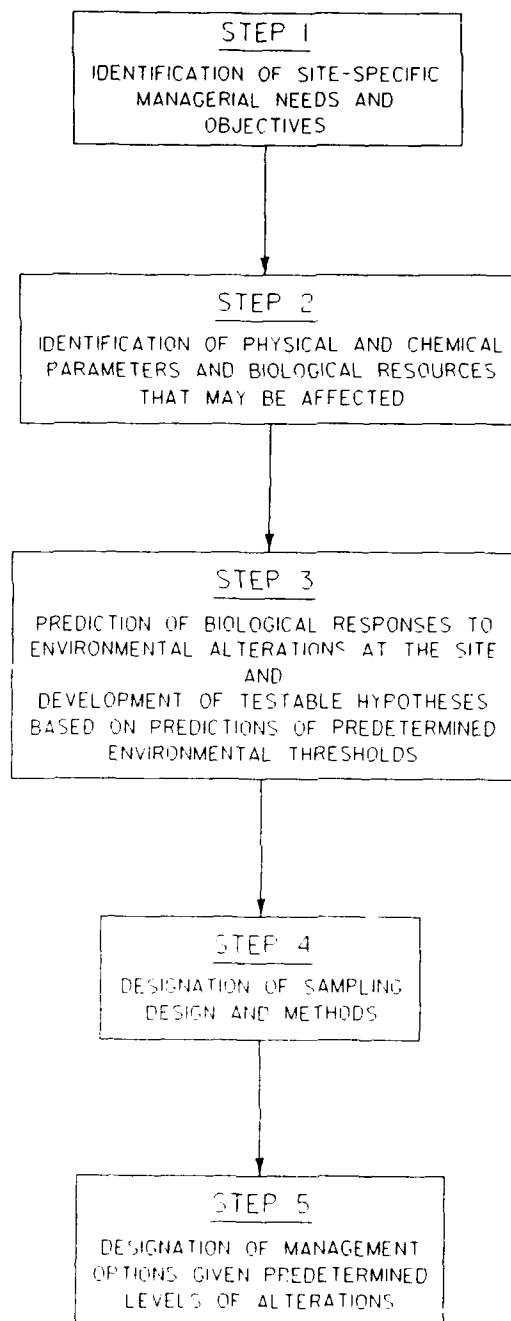


Figure 42. Generalized step-wise procedure for outlining a monitoring program (after Fredette et al. 1990)

Figure 43 depicts a monitoring approach suggested for use in monitoring ocean sites off Grays Harbor, Washington (Pearson 1987). Tier I activities include a bathymetric survey and sediment transport monitoring to determine whether the deposited material is resisting erosion. This is compatible with the expectation that significant impacts will not occur beyond the site boundaries unless the material crosses the boundary in substantial amounts. This is accomplished by producing a time-series of bathymetric maps revealing

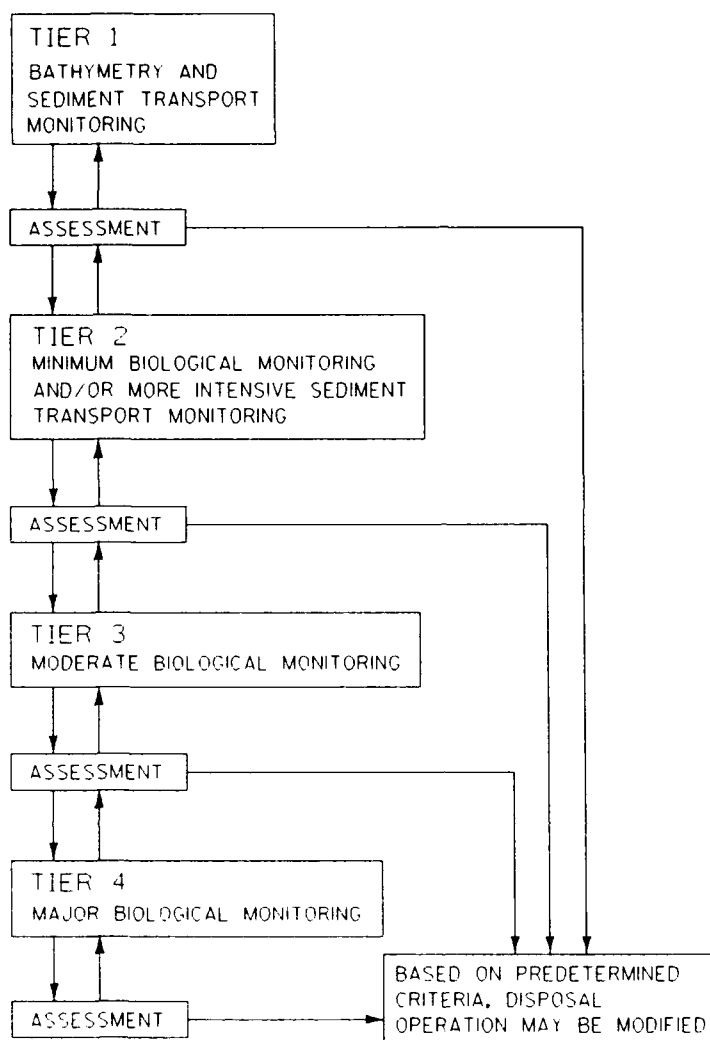


Figure 43. Generalized, tiered approach to monitoring disposal of dredged materials (after Pearson 1987)

the shape and size of the disposal mound, and by running a series of cross sections of the mound. These efforts will require use of a recording echosounding Fathometer and a precision positioning system (e.g., Microwave or GPS). Appropriate sediment sampling should also be carried out with analysis for texture and possibly total organic carbon. Tier II will very likely require more sediment transport monitoring, and it may be necessary to conduct TV tows and trawl runs to determine whether detectable impacts on major biological resources have occurred or are imminent.

In most situations, one will wish to evaluate the results of Tier I with consideration of predetermined thresholds for management action before instituting Tier II. By so doing it should be possible to ascertain whether the disposed material is acting as predicted. Such assessments will also give guidance on how intensive the sampling in Tier II should be. Also, even at this early stage, it may be possible to decide what change, if any, should be made in the disposal plan (e.g., reduce frequency and/or amount of material per disposal

or, possibly, abandon the site). In many cases, sampling beyond Tier II will not be required to achieve management decisions; however, if it is, the focus will be upon biological testing, including toxicity bioassays and bioaccumulation, with appropriate predetermined courses of action established.

The Basic Monitoring Program

The environmental monitoring programs in use today are generally designed to detect early signs of environmental impact near the site. The underlying assumption is simply that impacts will occur there before far-field effects, if any, can be detected. Obviously, this assumption is limited to dredged material.

It is quite possible that a monitoring program may consist solely of the measurement of physical parameters. In fact, as noted above, the initial stage of any biological monitoring program usually involves measurement of a physical parameter, such as bathymetry or granulometry. This is because biological effects result directly from the physical actions of the dredged material on the benthic community. Therefore, because biological impacts are generally linked to physical alterations, efforts should be made to coordinate physical and biological sampling efforts. For instance, measurements of sediment dispersion can assist in determining the placement of biological sampling stations. It is also possible that the first tier may be simply an initial evaluation of available information to establish whether there is "reason to believe" that contaminants are or are not present (Engler et al. 1988).

As noted in Figure 41, this first tier is commonly referred to as the "exclusion clause" (40 CFR 227.13 (b)). If there is no reason to believe that contaminants are present and if the dredged material is similar in grain size to the sediments of the site, no further testing is required. On the other hand, if there is reason to believe that contaminants are present or sufficient information is not available, a second evaluation (tier) in the form of a bulk sediment analysis may be performed.

If the bulk analysis shows that substantial concentrations of priority contaminants are present in the dredged material and there is reason to believe that they are bioavailable, a third tier of testing may be required. For dredged material this will generally involve a solid phase bioassay. Bioaccumulation can be a matter of concern. If so, this can be an extension of the third tier in which the survivors of the toxicity bioassays are used for bioaccumulation assessment.

An Expansion of Physical Measurements

Some site managers expand upon the initial physical measurements by determining the volume and location of disposed sediments within the site. It is usually considered critical to know whether the material is moving outside the site, and if so how much, how fast, and in what direction. To ascertain these things, good navigation and positioning equipment must be available. These are used to map the data derived from depth sounders, side-scan sonar, and subbottom profilers. Sediment sampling, including coring, is an essential part of most monitoring programs. More sophisticated investigations involve the use of sediment-profiling cameras (not efficient in very sandy sediments) and devices for determining engineering properties.

COMPARISON OF TIERED AND NONTIERED MONITORING PROGRAMS

Fredette et al. (1990) contrast the design of a tiered monitoring program with a non-tiered program, using the surf clam living near the site as the species of concern. In both programs the overall purpose is directed toward ensuring that the disposal will not cause an unacceptable decrease in population density of the surf clam.

Nontiered Program

The nontiered approach is based on the following concepts:

- a. The question is asked, Will disposed sediments have an unacceptable adverse biological effect on the population density of the surf clam?
- b. The null hypothesis is spelled out, viz., the changes in mean density of surf clams at various sampling sites are unrelated to changes in mean sediment particle size subsequent to disposal.
- c. If subsequent data analyses lead to a rejection of the null hypothesis, the manager would be faced with abandoning or moving the ocean site.

Note that the design of the program centered upon numerical changes in the resource, so the management decision could only be made after the decrease in population density became unacceptable.

Tiered Program

Aspects of the tiered approach are given below.

- a. Considerable knowledge is required about the biology of the species in focus and about its physical environment.
- b. It is a given condition that the surf clam thrives only in coarse-grained sediments and that water movements at the site can on occasion move the disposed fine-grained sediments. These parameters are the basis for the testable hypotheses that are arrayed in tiers based upon appropriate predictions.

Tier 1 null hypothesis

Mean sediment grain size at places where surf clams live remains unchanged during and after disposal. The action threshold would be a doubling of the silt-clay component (stated in percentages) relative to ambient. It was already established that such a percentage would be an adverse factor.

Sampling sediments is easy to accomplish, and texture can be determined quickly and inexpensively so that critical data are available to the manager in a short time. Thus:

- a. If the monitoring results support the null hypothesis, nothing more need be done at the time because no change in texture was occurring.
- b. If monitoring results call for rejection of the null hypothesis, the manager has two options:
 - (1) Cap the fine material with coarse sand.
 - (2) Call for implementation of the second tier.

Tier 2 null hypothesis

The tests in the second tier would shift to the surf clam, and might take the following form: the so-called health index of the surf clams (ratio of internal shell volume to tissue volume) is not negatively affected by the observed changes in sediment grain size. If the ratio decreased by more than a factor of 5, the critical threshold would be violated (Fredette et al. 1986). Sampling for this parameter is fairly simple and need not be done at close intervals. Key concepts are:

- a. If the sampling results support the null hypothesis, nothing more need be done, because the health of the clams has not been adversely affected.
- b. If the null hypothesis is rejected, we need to know whether the effects are serious enough to cause a reduction in population density.

Tier 3 null hypothesis

The null hypothesis in the third more difficult and costly tier would probably take the following form: changes in mean density of surf clams at several sampling stations are unrelated to changes in mean sediment particle size as a result of disposals. The critical threshold, based upon published information, might be a drop of density below one individual per square meter, as calculated with data derived from 20 to 40 stations and compared with baseline. In the Tier 3 analysis:

- a. If sampling results support the null hypothesis, no change in the disposal program is required.
- b. If the null hypothesis is rejected, disposal at the site would have to be changed or prohibited.

If threshold violation of a given tier does occur, the manager should not only move to the next highest tier but also reexamine the basis for predicting that adverse impacts would not occur. Obviously, if the violation is a serious one, disposal operations can either be modified or terminated pending results of tests from the higher tier. If the latter results are favorable and since the threshold violation indicated only a potential for impact, the manager may opt to return to the original disposal mode.

When establishing thresholds of change associated with the disposal of dredged material, one must consider how disposal can impact a given species of living resource. Conditions that should be noted include:

- a. Burial by dredged sediments falling to the seabed, resulting in crushing, suffocation, or a thick overburden of sediment through which the organism can no longer escape to the surface. This is not a serious threat to mobile benthopelagic or large, mobile epifaunal species, but may be to any burrowing species or to a nonmobile species.
- b. Clogging of gills by sharp silt or clay particles, which can cause either transitory or permanent damage to respiratory systems. This is more of a threat to small species than to fishes or large, mobile invertebrates.

MONITORING OF POSTDISPOSAL SUCCESSION OF THE INFAUNA

Assessment of Secondary Production with the Sediment Profiler

Based on the critical need for disposal site managers to have access to the results of monitoring in a timely fashion so that changes in the disposal operation can be instituted when adverse impacts are seen to be occurring, some investigators have constructed monitoring protocols employing the sediment profiler (Rhoads and Germano 1986, Scott et al. 1987, Fredette et al. 1990). The techniques being developed, particularly but not solely in conjunction with the DAMOS project of the CE New England Division, are very promising, especially in soft sediments where the profiler is most efficient. These protocols are constructed from four considerations that are arranged in such a way as to reflect a tiered monitoring program:

- a. Measurable transport of dredged material with or without contained pollutants outside of the disposal site is not occurring.
- b. Benthic recolonization of the disposal mound by expected ecotypes is proceeding within the normal range of time.
- c. No significant increases are noted in concentration of pollutants in the tissues of selected macroinfaunal species as compared with baseline data and those derived from the reference site.
- d. Food web biomagnification of pollutants is not occurring.

Each of the above tiers can be restated where necessary in the form of a quantitative null hypothesis which in turn can provide the basis for a definitive threshold. As presented in the following, note that each successive tier carries increased costs of both time and money:

- a. Mean grain size outside but near the site boundaries remains unchanged after disposal operations.
Hypothetical threshold. A more than 15-percent increase in the fine components is not acceptable since fines are inimical to species of concern.
- b. Dredged material disposal will result in increased benthic production (secondary production) within the site, as compared with ambient conditions. This is because of the assimilable organics in the dredged material.
Hypothetical threshold. A drop of 25 percent or more in secondary production a reasonable time after disposal would trigger further investigations.
- c. Selected infaunal species do not exhibit significant increases in tissue pollutants, as compared with baseline and control measurements.
Hypothetical threshold. Increases in concentrations of priority contaminants in tissue of prey species approaching 0.01 of the LC₅₀ would be cause for disposal modifications and assessments.
- d. Top predators in the food web do not evidence high concentration factors for selected contaminants.
Hypothetical threshold. Concentrations of priority contaminants in edible tissues of predators attaining or exceeding the FDA (Food and Drug Administration)

Action Level, would be cause for prohibiting further disposal and capping the existing mound.

We note that each of the above tiers has its own critical threshold (the above are purely arbitrary exemplifications). If it is not violated, the null hypothesis is accepted and nothing further will have to be done, i.e., disposal can proceed. If, however, the threshold is violated and the null hypothesis rejected, a disposal modification response from the site manager is called for. Such modifications can range from reducing the rate of disposal to actual closure of the site.

Successional Stages in Recovery After Disposal

As Rhoads and Germano (1986) have pointed out, the relationships between types of organisms and sediment (after natural or man-made disturbances) have time and function characteristics that are both predictable and similar worldwide. The time characteristic involves successional stages in the progressive development toward a climax community; the similarity characteristic points to the fact that although different taxa may be involved in the successional stages following a disturbance, the specific functional types are very much alike (see Figure 44).

Following a major disturbance such as the deposition of volumes of sediments, the new sediment surfaces are populated by pioneering seres of a given functional type. Thus, one can infer dynamics by an analysis of community structure. The latter can be accomplished by use of the sediment profiler (Rhoads and Germano 1986). These authors suggest that the organisms that repopulate an area of disturbed seabed on the continental shelf can be assigned to three stages. The pioneering sere is constituted of small tubiculous polychaetes (and/or oligochaetes) and the ubiquitous bivalve *Mulinia* that live at or near the sediment surface. Thus, such cosmopolitan genera as *Mediomastus*, *Polydora*, *Strebliospio*, and *Mulinia* are the principal Stage I taxa. These feed on labile detritus located at or near the surface. One reason they become so densely aggregated on dredged material mounds is that the material contains so much available organic matter, especially if it is removed from an estuary.

Subsequent Recovery Stages and Redox Penetration

As recovery of the disturbed seabed continues, a transitional stage, a Stage II sere, may appear. This usually is represented by tubiculous amphipods, as well as some molluscs and polychaetes (Rhoads and Germano 1986). The area of bioturbation deepens with a consequent increase in thickness of the positive redox layer (perhaps from 0.5 to 1.5 cm). Stage III seres develop after passage of several months and are constituted of deeply burrowing (3 cm or more) tubiculous infauna which feed head-down. With the sediment profiler these areas of subsurface feeding are recognized as water-filled pockets called feeding voids. The dominant biota in Stage III are the polychaete *Nephtys* as well as malpighianid, pectinid, and orbinid polychaetes, caudate holothurians (e.g., *Molpadia*), protobranch bivalves (e.g., *Yoldia* and *Nucula*), some infaunal ophiuroids, and irregular sea urchins (Rhoads and Germano 1982). In many cases there will not be a complete separation of stage taxa, since Stage I species may be associated, albeit in reduced numbers, with Stage III seres.

The primary advantages of the sediment-profiling camera are that it can provide both physicochemical and biological reconnaissance data in a short time and at a comparatively low cost. It is emphasized, however, that this instrument should be used in conjunction with more traditional benthic sampling protocols, such as use of the Gray-O'Hara Grab and subsequent sorting and laboratory analysis (Fredette et al. 1990).

FOR NONCAPPING MOUND, DREDGED MATERIAL
DISPOSAL WILL RESULT IN BENTHIC PRODUCTION
≥ AMBIENT CONDITION ON THE MOUND

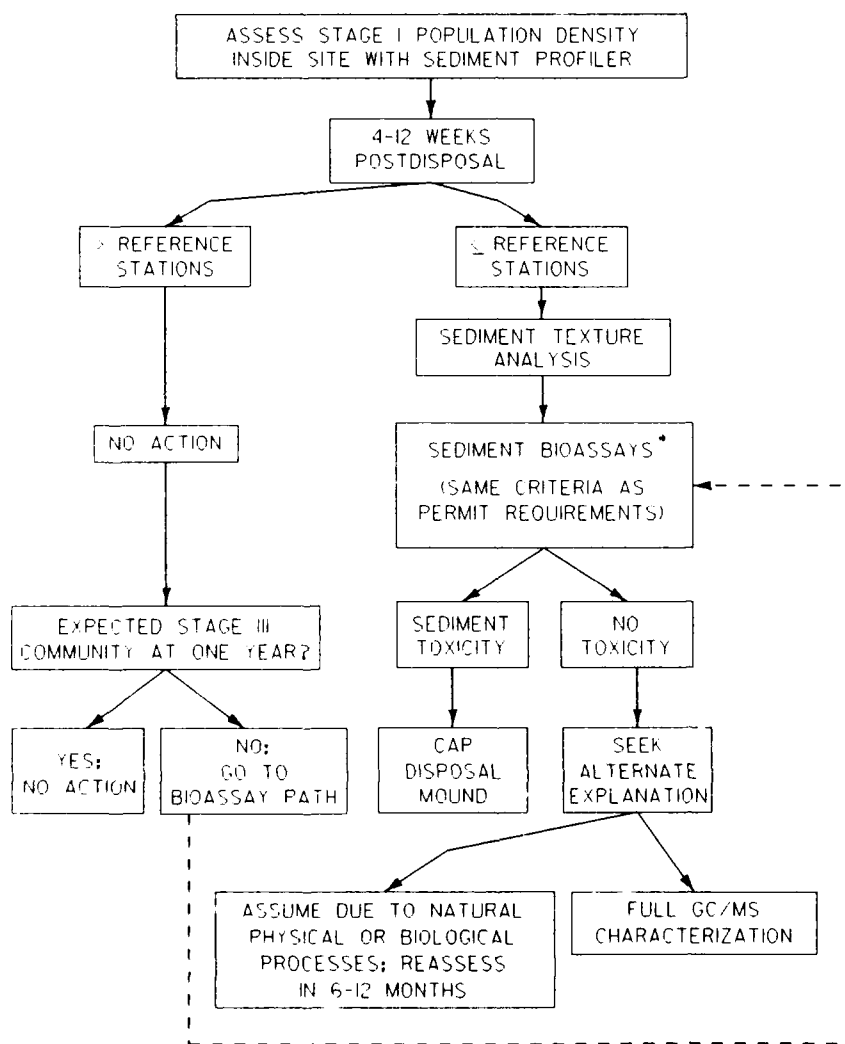


Figure 44. Draft decision tree for conditions on a noncapping dredged material mound using a sediment profiler (based on DAMOS project)

In some cases it may be necessary to monitor a capped mound of contaminated dredged material. In this instance one will need to use a piston or gravity corer in addition to the sediment profiler in order to determine both the physical integrity of the cap and its effectiveness as a barrier to the migration of contaminants from the mound into and through the cap (Figure 45).

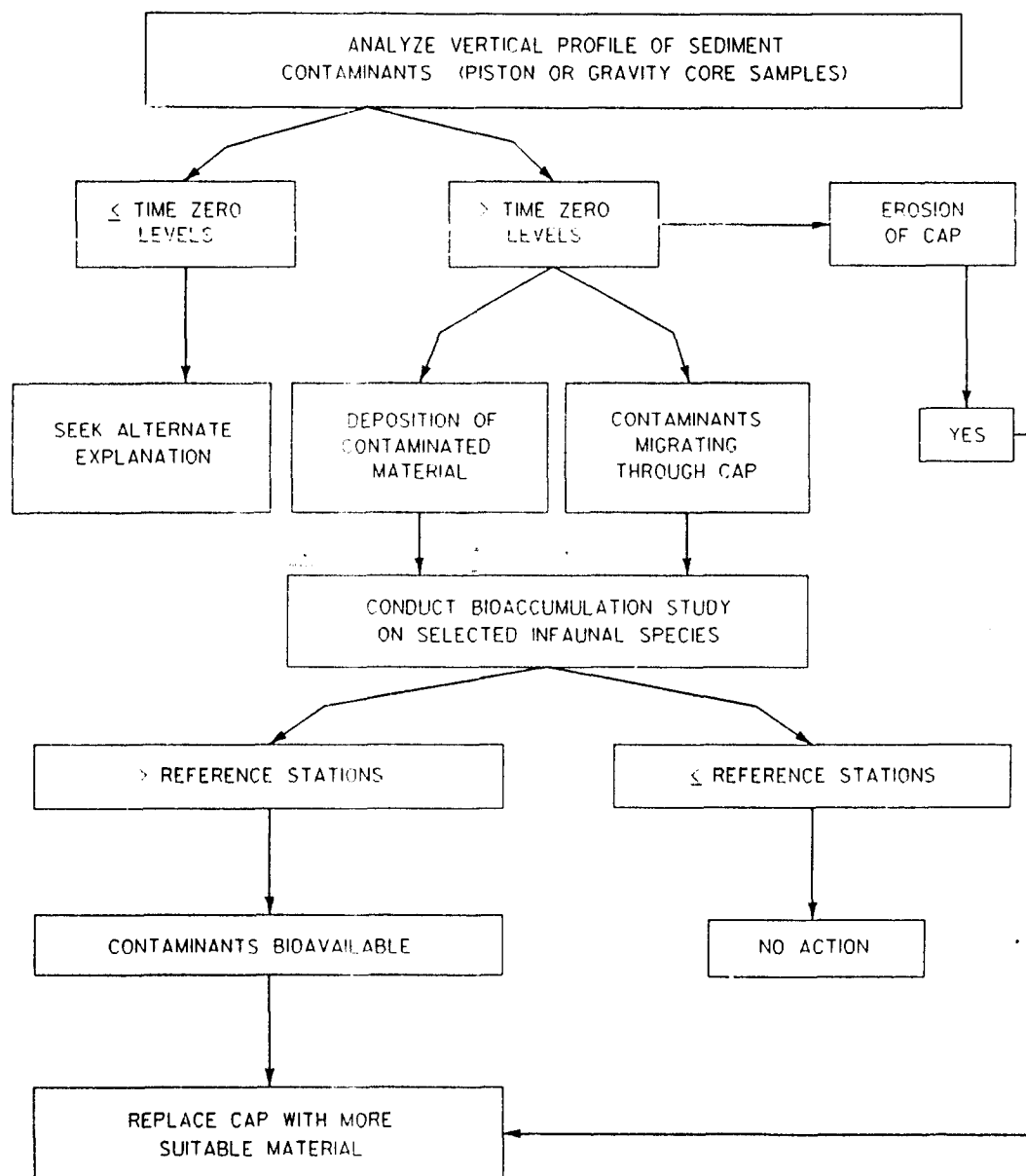


Figure 45. Draft decision tree for cap contamination investigation

MONITORING THE FISHERY POTENTIAL OF THE DREDGED MATERIAL MOUND

As we have pointed out, the infaunal invertebrate organisms that comprise the successional series of recently disposed dredged material are a vital source of food for several species of demersal and benthopelagic fishes. The growth in the populations of these invertebrates constitutes secondary production, which is cropped by the fishes and larger mobile invertebrates. The populations of the pioneering species, the opportunistic polychaetes, have a high rate of increase which tends to be concentrated near the sediment surface where it is available to fishes. Stage III taxa may not comprise as important a food source since they live deeper in the sediments. The distribution of each of the successional stages can be mapped through use of the sediment profiler (Rhoads and Germano 1986). To assess the state of these successional series and the importance of each to commercial finfisheries, one may follow the protocol of the Benthic Resource Assessment Technique (BRAT) of Lunz and Kendall (1982). This involves quantitative sampling of demersal fish and potential invertebrate prey species from the different infaunal successional stages that are mapped. The size-class distribution of major taxa of ingested prey is determined from fish stomach contents and is compared with the size-class distribution of prey species in regard to depth in the sediment for each type of successional assemblage sampled (Figure 46). In general, with the passage of time following disposal of dredged material, there is an increase in both the size of the animals and the depth at which they live. Their depth distribution in the sediments is determined by separately sieving strata removed from vertically partitioned box cores.

BENTHIC RESOURCES ASSESSMENT TECHNIQUE (BRAT)

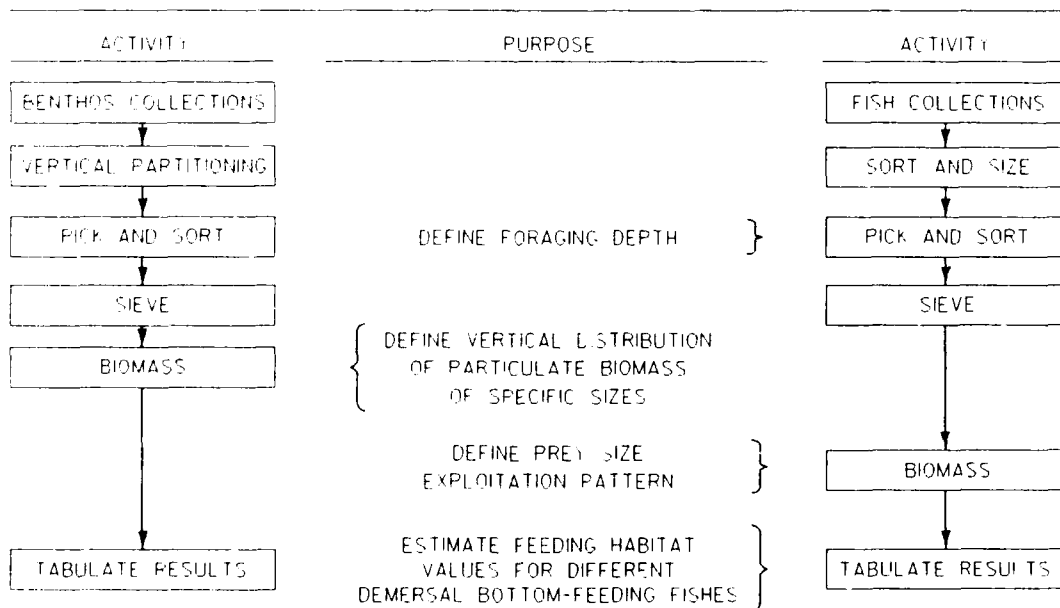


Figure 46. Flowchart of steps required for the BRAT

BRAT as a Monitor of Fish Forage Value of Dredged Material

In the BRAT, the foraging depths of a given species of fish at different ages and seasons are examined to connect it with its prey species (Figure 47). Knowledge about these relationships allows one to estimate the portion of a particular benthic assemblage that is available to the given species of fish (Lunz et al. 1988). Having these data available, one can calculate the fish forage value of the seafloor before disposal of dredged material and can even predict the time sequence of postdisposal recovery. The BRAT can be used to verify that a given disposal strategy is actually maximizing the secondary production of fishfood species in the seafloor (see Part VI for a more complete discussion).

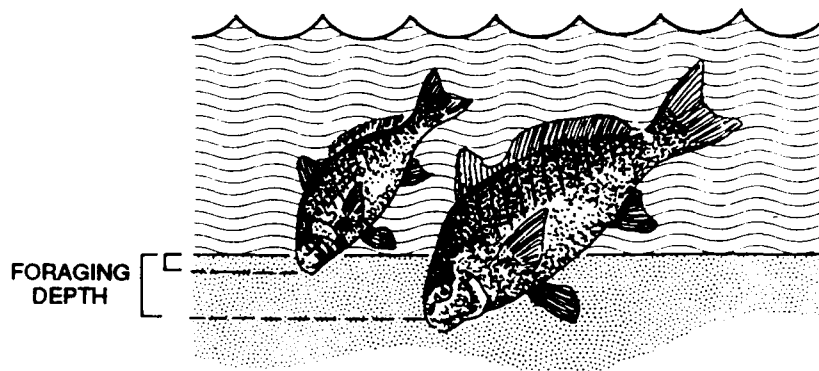


Figure 47. BRAT takes into consideration the foraging depth of a given predator, which is defined as the depth in the sediment column to which prey are removed (after Lunz et al. 1988)

Monitoring Must Include Chronic Effects

With increasing pressures from some environmental groups against ocean disposal of sewage sludges and selected industrial wastes, it is imperative that ocean disposal sites for dredged material be situated where effective monitoring programs and relief measures can be instituted when indicated by responses of target resources. There is no doubt that efforts to ban the ocean disposal of dredged material will increase in intensity and sophistication in ensuing years. Those who support ocean disposal must be prepared to demonstrate with hard data derived from monitoring that such disposals do not cause unacceptable adverse impacts upon marine ecosystems. It is clear that one must be prepared to demonstrate that cognizance has been taken of chronic as well as acute effects. A summary of such predictive methodologies can be found in reports on the results of the CE's Field Verification Program. A summary of methods and results can be found in Gentile et al. (1988).

WHEN ALL ELSE FAILS

In 1978 the CE established the Dredging Operations Technical Support (DOTS) Program as a technology transfer vehicle to assist the field in implementing results from research, development, and field demonstration programs. Assistance under DOTS is

provided to all CE elements, including Districts, Divisions, and Headquarters, to handle environmental issues associated with operations and maintenance dredging and dredged material disposal.

The DOTS Program direct "hands-on" assistance includes, but is not limited to, addressing technical issues on a one-on-one basis; preparing briefings and seminars; developing study plans and project monitoring strategies; preparing guidelines and criteria; technically reviewing reports; developing management plans for disposal areas; and assisting in projects involving litigation. DOTS assistance is only a telephone call away for those CE elements needing rapid assistance in solving dredging and dredged material disposal problems.

The DOTS focus has two objectives: to continue to address the field's high-priority technology application needs and to oversee the application of a complete long-term management strategy for evaluating and assessing various dredged material disposal alternatives. As environmental management becomes a routine part of field applications, the CE faces new disposal management decisions brought on by more environmentally complex problems and regulations. Based on these changing field needs, recommendations from the Chief of Engineers' Environmental Advisory Board, and guidance from the field, a complete Dredged Material Management structure guides the assessment and technical application tasks of the DOTS Program. These "tasks" are generally 1- or 2-year efforts aimed at developing practical "hands-on" field guidance on existing technology as opposed to research efforts that are concerned with developing the technology.

For additional information concerning DOTS assistance, call (601)634-3624 or write:

Dr. Robert M. Engler/CEWES-EP-D
US Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

REFERENCES

- Anders, Fred J., Reed, David W., Stauble, Donald K., and Hansen, Mark. Interactive Sediment Analysis Program (ISAP): A user's guide. Instruction Report (in preparation), US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Bagnold, R.A. 1940. Beach formation by waves; some model experiments in a wave tank. *J. Instit. Civil Eng.* 15:27-52.
- Bailey, E.H. 1966. Geology of Northern California. US Geol. Surv. Calif. Div. of Mines and Geology Bull. 190.
- Basco, D.R., A.H. Bouma, and W.A. Dunlap. 1974. Assessment of the factors controlling the long-term fate of dredged material deposited in confined subaqueous disposal areas. Contract Report D-74-8. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Bokuniewicz, H., and R.B. Gordon. 1980. Deposition of dredged sediment at open-water sites. *Estuarine and Coastal Marine Science* 10:289-304.
- Bokuniewicz, H., J.A. Gebert, R.B. Gordon, J.L. Higgins, T. Kaminsky, C.C. Pilbeam, M. Reed, and C.B. Tuttle. 1978. Field study of the mechanics of the placement of dredged material at open-water disposal sites. Technical Report D-78-7. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Brandsma, M.G., and D.J. Divoky. 1976. Development of models for prediction of short-term fate of dredged material in the estuarine environment. Contract Report D-76-5. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Bright, T.J., and L.H. Pequegnat. 1974. Biota of the West Flower Garden Bank. Gulf Publ. Co., Houston, TX.
- Carr, W.E.S., and C.A. Adams. 1973. Food habits of juvenile marine fishes occupying seagrass beds in the estuarine zone near Crystal River, Florida. *Trans. Amer. Fisheries Society* 102:511-540.
- Clarke, D.G., and J.D. Lunz. 1985. The benthic resources assessment technique in theory and practice. Proceedings of the US Environmental Protection Agency Ninth Annual Environmental Review Conference, Atlanta, GA, 14-15 November 1985.
- Clausner, J.E., and R.M. Engler. 1988. Use of seabed drifters for locating and monitoring dredged material placement sites. Environmental Effects of Dredging Technical Note EEDP-01-12. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Clausner, J.E., W.A. Birkemeier, and G.R. Clark. 1986. Field comparison of four near-shore survey systems. Miscellaneous Paper CERC-86-6. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Coleman, J.M., and S.M. Gagliano. 1964. Cyclic sedimentation in the Mississippi River deltaic plain. *Trans. Gulf Coast Assoc. Geol. Soc.* 14:(6):7-84.

- Cooley, W.W., and P.R. Lohnes. 1971. Multivariate data analysis. Wiley Press, New York.
- Cooper, R.A. 1970. Retention of marks, their effects on growth, behavior, and migrations of the American lobster, *Homarus americanus*. Trans. Am. Fish. Soc. 99:409.
- Curry, J.R. 1960. Sediments and history of Holocene transgression, continental shelf, Northwest Gulf of Mexico. Pages 221-266 in F.P. Shepard, F.B. Packer and Tj.H. Van Andel (eds.), Recent sediments, Northwest Gulf of Mexico. Amer. Assoc. Petrol. Geol., Tulsa, OK.
- Davies, D.L. 1971. Design and analysis of industrial experiments. Hofner, New York.
- Dietz, R.S., and J.C. Holden. 1970. The breakup of Pangaea. Sci. Amer. 223(4):30-41.
- Drake, D.E. 1976. Suspended sediment transport and mud deposition on continental shelves. Pages 127-158 in D.J. Stanley and D.J.P. Swift (eds.), Marine sediment transport and environmental management. Wiley-Interscience, New York.
- Eisenhart, C., M.W. Hastay, and W.A. Wallis. 1947. Techniques of statistical analysis, Chap. 15. McGraw Hill, New York.
- Emery, K.O. 1969. The continental shelves. Pages 39-52 in The ocean; A Scientific American Book. W.H. Freeman and Co., San Francisco, CA.
- Emery, K.O., and E. Uchupi. 1972. Western North Atlantic Ocean: Topography, rocks, structure, water, life, and sediments. Amer. Assoc. Petrol. Geol. Mem. 17. Tulsa, OK.
- Engler, R.M., T. Wright, C.R. Lee, and T.M. Dillon. 1988. Corps of Engineers procedures and policies on dredging and dredged material disposal (The Federal Standard). Environmental Effects of Dredging Technical Note EEDP-04-8. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Fingl, E., and D.M. Woodbury. 1965. General principles. Pages 1-36 in L.S. Goodman and A. Gilman (eds.), The pharmacological basis of therapeutics, 3rd ed. Macmillan, New York.
- Folk, R.L. 1974. Petrology of sedimentary rocks. Hemphill Publ. Co., Austin, TX.
- Francingues, N.R., M.R. Palermo, C.R. Lee, and R.K. Peddicord. 1985. Management strategy for disposal of dredged material: Contaminant testing and controls. Miscellaneous Paper D-85-1. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Fredette, T.J., G. Anderson, B.S. Payne, and J.D. Lunz. 1986. Biological monitoring of open-water dredged material disposal sites. Proc. IEEE Oceans 86 Conference, Washington, DC.
- Fredette, T.J., D.A. Nelson, T. Miller-Way, J.A. Adari, V.A. Sotler, and J.E. Clausner. 1990. Selected Tools and Techniques for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites. Technical Report D-90-xx. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Fullard, H., and H.C. Darby. 1970. Aldine University Atlas. Aldine Publ. Co., Chicago.

- Gallaway, B.J., L.R. Martin, and R.L. Howard, eds. 1988. Northern Gulf of Mexico Continental Slope Study, Annual Report: Year 3; Vol II: Technical Narrative. Annual Report submitted to the Minerals Management Service, New Orleans, LA.
- Gambrell, R.P., R.A. Khalid, and W.H. Patrick, Jr. 1978. Disposal alternatives for contaminated dredged material as a management tool to minimize adverse environmental effects. Technical Report DS-78-8. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Gentile, J.H., et al. 1988. Synthesis of Research Results: Applicability and Field Verification of Predictive Methodologies for Aquatic Dredged Material Disposal. Technical Report D-88-5. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Germano, J.D., and D.C. Rhoads. 1984 (Nov). REMOTS: Sediment profiling at the field verification program (FVP) disposal site. Dredging '84, Waterway, Port, Coastal and Ocean Division, American Society of Civil Engineers, Clearwater Beach, FL.
- Gorsline, D.S. 1975. A review of the marine geology of the Southern California offshore region. Pages 63-81 in R.J. Lavernberg and S.A. Earle (eds.), Recommendations for baseline research in Southern California relative to offshore resource development; Proceedings of a Conference and Workshop. Bureau of Land Management, US Department of the Interior, Washington, DC.
- Green, R.H. 1984. Some guidelines for the design of biological monitoring programs in the marine environment. Concepts in Marine Pollution Measurement. Maryland Sea Grant College, University of Maryland, College Park, MD.
- Hollister, C.D. 1973. Atlantic continental shelf and slope of the United States--texture of surface sediments from New Jersey to southern Florida. US Geol. Surv. Prof. Paper 629-M.
- Hurlbert, S.H. 1971. The nonconcept of species diversity: A critique and alternative parameters. Ecology 52:577-586.
- Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs, Vol 54, pp 187-211.
- Komar, P.D. 1976. The transport of cohesionless sediments on continental shelves. In D.J. Stanley and D.J.P. Swift (eds.), Marine sediment transport and environmental management. John Wiley and Sons, New York.
- Komar, P.D., and M.C. Miller. 1975. Sediment threshold under oscillatory waves. Pages 756-775 in Proc. 14th Conf. Coastal Eng., American Society of Civil Engineers, New York.
- Krebs, C.J. 1989. Ecological methodology. Harper and Row, New York.
- Kulm, L.D., and G.A. Fowler. 1970. Study of the continental margin off the state of Oregon. US Geol. Surv. Tech. Rept. No. 4 (Ref. No. 70-2). Dept. of Oceanography, Oregon State Univ., Corvallis.

- LaSalle, M.W., D.A. Nelson, and J.E. Clausner. 1988. Physical and biological monitoring of aquatic dredged material disposal sites. Environmental Effects of Dredging Information Exchange Bulletin, Vol D-88-2. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Lunz, J.D., and D.R. Kendall. 1982 (Sep). Benthic resource assessment technique, a method of quantifying the effects of benthic community changes on fish resources. Oceans '82. NOAA, Office of Marine Pollution Assessment, Rockville, MD, pp 1021-1027.
- Lunz, J.D., D.A. Nelson, D.G. Clarke, and E.J. Pullen. 1988. Long-term disposal site problems and conflicts: Evaluating seafloor impacts using the benthic resource assessment technique (BRAT). Proc. of the North Atlantic Regional Conference; Beneficial Uses of Dredged Material, Mary C. Landin (ed). US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- MacArthur, R.H. 1965. Patterns of species diversity. Biol. Rev. 40:510-533.
- Macek, K.J., S.R. Petrocelli, and B.H. Sleight III. 1979. Considerations in assessing the potential for, and significance of, biomagnification of chemical residues in aquatic food chains. Special Technical Publication 667. American Society for Testing and Materials, Philadelphia, PA.
- Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, NJ.
- Mathis, D.B. and B.S. Payne. 1984. Guidance for designation of ocean sites for dredged material disposal. Environmental Effects of Dredging Information Exchange Bulletin, Vol D-84-2. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- McIntyre, A.D. 1971. Introduction: Design of sampling programmes. International Biological Program Handbook No. 16:1-11.
- Milliman, J.D., O.H. Pilkey, and D.A. Ross. 1972. Sediments of the continental margin off the eastern United States. Geol. Soc. Amer. Bull. 83:1315-1334.
- Moore, D.G., and G.A. Shumway. 1959. Sediment thickness and physical properties: Pigeon Point Shelf, California. J. Geophys. Res. 64(3):367-374.
- Moriarty, F. 1983. Ecotoxicology. Academic Press, New York.
- Mountford, M.D. 1962. An index of similarity and its application to classificatory problems. Pages 43-55 in P.W. Murphy (ed.), Progress in soil zoology. Butterworth, London.
- Parker, R.H. 1975. The study of benthic communities. Elsevier Scientific Pub., New York.
- Pearson, W.H. 1987. Conceptual plan for the management and monitoring of two ocean disposal sites off Grays Harbor, Washington. Prepared by Battelle/Marine Research Laboratory, Sequim, WA, for US Army Engineer District, Seattle, Seattle, WA.
- Peet, R.K. 1974. The measurement of species diversity. Ann. Rev. Ecol. Syst. 5:285-307.

- Pequegnat, W.E. 1972. A deep bottom current on the Mississippi Cone. Pages 65-87 in L.R.A. Capurro and J.L. Reids (eds.), *Contributions on the physical oceanography of the Gulf of Mexico*. Texas A&M University, Oceanographic Studies; Vol 2. Gulf Publishing, Houston, TX.
- Pequegnat, W.E. 1984. Specifications of a model ocean disposal site for dredged material. Pages 167-183 in Thomas R. Patin (ed.), *Management of Bottom Sediments Containing Toxic Substances*. Proc. 8th US/Japan Experts Meeting. US Army Corps of Engineers Water Resources Support Center, Fort Belvoir, VA.
- Pequegnat, W.E. 1986. An overview of the scientific and technical aspects of dredged material disposal in the marine environment. Prepared for Office of Technology Assessment, US Congress, Washington, DC.
- Pequegnat, W.E., and W.B. Sikora. 1977. Meiofauna project. Environmental studies, South Texas outer continental shelf, biology and chemistry. Prepared by Texas A&M University, College Station, TX, for Bureau of Land Management, US Department of the Interior, Washington, DC.
- Pequegnat, W.E., and W.B. Sikora. 1978. The meiofauna and macroinfauna from submarine banks in the Gulf of Mexico, Chap. 5. *Northwestern Gulf of Mexico Topographic Features Study*. Prepared by Texas A&M University, College Station, TX, for Bureau of Land Management, US Department of the Interior, Washington, DC.
- Pequegnat, W.E., and W.B. Sikora. 1979. Meiofauna project. Environmental studies, South Texas outer continental shelf, biology and chemistry. Prepared by Texas A&M University, College Station, TX, for Bureau of Land Management, US Department of the Interior, Washington, DC.
- Pequegnat, W.E., and C. Venn. 1979. Meiofauna project. Data synthesis of environmental studies, South Texas outer continental shelf, biology and chemistry. Prepared for Bureau of Land Management, US Department of the Interior, Washington, DC.
- Pequegnat, W.E., D.D. Smith, R.M. Darnell, B.J. Presley, and R.O. Reed. 1978. An assessment of the potential impact of dredged material disposal in the open ocean. Technical Report D-78-2. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Pequegnat, W.E., L.H. Pequegnat, B.M. James, E.A. Kennedy, R.R. Fay, and A.D. Fredericks. 1981. Procedural guide for designation surveys of ocean dredged material disposal sites. Technical Report EL-81-1, prepared by TerEco Corporation for the US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Pequegnat, W.E., L.H. Pequegnat, J.A. Kleypas, B.M. James, E.A. Kennedy, and G.F. Hubbard. 1983. The ecological communities of the continental slope and adjacent regimes of the northern Gulf of Mexico. Prepared for Minerals Management Service, US Department of the Interior, Washington, DC.
- Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. *J. Theor. Biol.* 13:131-144.

- Postma, H. 1967. Sediment transport and sedimentation in the estuarine environment. Pages 158-179 in G.H. Lauff (ed.), *Estuaries*. AAAS Publication No. 83, Amer. Assoc. Adv. Sci., Washington, DC.
- Revelas, E.C., J.D. Germano, and D.C. Rhoads. 1987. REMOTS: Reconnaissance of benthic environments. *Coastal Zone '87*. Seattle, WA. Waterways Division, American Society of Civil Engineers.
- Rhoads, D.C., and J.D. Germano. 1982. Characterization of organism-sediment relations using sediment profile imaging: An efficient method of remote ecological monitoring of the seafloor (REMOTS System). Pages 115-128 in *Marine Ecology Progress Series*, Vol 8.
- Rhoads, D.C., and J.D. Germano. 1986. Interpreting long-term changes in benthic community structure: A new protocol. *Hydrobiologica* 142:291-308.
- Rinkel, M.D., and J.I. Jones. 1973. ESCAROSA I. An oceanographic survey of the Florida territorial sea of Escambia and Santa Rosa Counties. Prepared by SUSIO and the Florida Coastal Coordinating Council.
- Romesburg, H.C. 1984. Cluster analysis for researchers. Lifetime Learning Publications, Belmont, CA.
- Saila, S.B., R.A. Pikanowski, and D.S. Vaughan. 1976. Optimum allocation strategies for sampling benthos in the New York Bight. *Estuarine and Coastal Marine Science* 4:119-128.
- Sanders, H.L. 1968. Marine benthic diversity: A comparative study. *Amer. Nat.* 102:243-383.
- Saucier, R.T., C.C. Calhoun, R.M. Engler, T.R. Patin, and H.K. Smith. 1978. Executive overviews and detailed summary for the Dredged Material Research Program, Technical Report DS-78-22. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Schlee, J. 1973. Atlantic continental shelf and slope of the United States--sediment texture of the northeastern part. *US Geol. Surv. Prof. Paper* 529-L.
- Scott, J., D. Rhoads, J. Rosen, S. Pratt, and J. Gentile. 1987. Impact of open-water disposal of Black Rock Harbor dredged material on benthic recolonization at the FVP site. Technical Report D-87-4. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Shepard, F.P., and D.L. Inman. 1950. Nearshore circulation related to bottom topography and wave refraction. *Trans. Am. Geophys. Union* 31(4):555-565.
- Simberloff, D. 1978. Use of rarefaction and related methods in ecology. Pages 150-165 in K.L. Dickson, J. Cairns, and R.J. Livingston (eds.), *Biological data in water pollution assessment: Quantitative and statistical analyses*. STP 652, American Society for Testing and Materials, Philadelphia, PA.
- Smith, W., and J.F. Grassle. 1977. Sampling properties of a family of diversity measures. *Biometrics* 33(2):283-292.

- Sneath, P.H.A., and R.R. Sokal. 1973. Numerical taxonomy. W.H. Freeman Company, San Francisco, CA.
- Snedecor, G.W., and W.G. Cochran. 1956. Statistical methods, 6th ed. Iowa State College Press, Ames, IA.
- Sokal, R.R., and F.J. Rohlf. 1969. Biometry. W.H. Freeman Company, San Francisco, CA.
- Stewart-Oaten, A., W.W. Murdoch, and K.R. Parker. 1986. Environmental impact assessment: Pseudoreplication in time? *Ecology* 67:929-940.
- Strickland, J.D.H., and T.R. Parsons. 1972. A manual of sea water analogies, rev. ed. Fish. Res. Bd. Can. Bull. No. 125.
- Tavolaro, J.F. 1987. Sediment budget study for clamshell dredging and disposal activities. US Army Engineer District, New York, New York, NY.
- Templeman, W. 1935. Lobster tagging in the Gulf of St. Lawrence. *J. Biol. Bd. Can.* 1:269.
- Tieh, T.T., T.E. Pyle, D.H. Eggler, and R.A. Nelson. 1973. Chemical variations in sedimentary facies of an inner continental shelf environment, northern Gulf of Mexico. *Sedimentary Geol.* 9:101-115.
- Uchupi, E. 1968. Atlantic continental shelf and slope of the United States--physiography. *US Geol. Surv. Prof. Paper* 529-C.
- Uchupi, E., and K.O. Emery. 1963. The continental slope between San Francisco and Cedros Island, Mexico. *Deep-Sea Res.* 10:397-447.
- Upshaw, G.F., W.B. Creath, and F.L. Brooks. 1966. Sediments and microfauna off the coasts of Mississippi and adjacent states. *Miss. Geol. Surv. Bull.* 106.
- US Department of the Interior, Bureau of Land Management. 1977. Draft environmental impact statement for proposed 1977 OCS oil and gas lease sale #43. U.S. Government Printing Office, Washington, DC.
- US Environmental Protection Agency. 1976. Methods for chemical analysis of water and wastes. EPA-625-16-74-003a. Environmental Monitoring and Support Laboratory. Environmental Research Center, Cincinnati, OH.
- USEPA/USACE. 1984(May). "General Approach to Designation Studies for Ocean Dredged Material Disposal Sites," published by US Army Corps of Engineers Water Resources Support Center, Fort Belvoir, VA.
- USEPA/USACE. 1990. "Draft Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters," EPA-503-8-90/002, Office of Marine and Estuarine Protection, Washington, DC.
- Walker, D.L. 1987. Future prospects for water quality management. Internat. Conf. on Environmental Protection of the North Sea, WRC Environment. 24-27 March 1987, International Maritime Organization, London.
- Wilkinson, Leland. 1987. SYSTAT: The system for statistics. SYSTAT, Inc., Evanston, IL.

- Williams, C.B. 1953. The relative abundance of different species in a wild animal population. *J. Animal Ecol.* 22:14-31.
- Wright, T.D. 1978. Aquatic dredged material disposal impacts. Technical Report DS-78-1. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Zeller, R.W., and Wastler, T.A. 1986. Tiered ocean disposal monitoring will minimize data requirements. *Proc., IEEE Oceans '86 Conference*, Washington, DC, pp 1004-1009.

APPENDIX A: THE NATURE OF DREDGED MATERIAL

Note: This appendix is designed to brief the reader on those components of typical dredged material that account for its ability to sequester contaminants so as to reduce their bioavailability and possible toxicity.

THE NATURE OF DREDGED MATERIAL

DEFINITION

Dredged material is a complex mixture of water, containing dissolved substances and inorganic and organic solids that have been removed from the bottom of rivers, lakes, estuaries or oceans by hydraulic, mechanical, or pneumatic equipment. Texturally, the dredged sediments can range from muds to gravels and boulders, but generally they are a mixture of sands, silts, and clays. Most dredged material is considered to be unpolluted and is thus environmentally acceptable for disposal in marine ecosystems without the risk of causing unacceptable adverse environmental impacts. Even some dredged materials that contain more than trace amounts of toxic metals or organic compounds can be disposed of safely in the marine environment, because they possess components that are capable of binding the toxicants so that they are not available to the biota. This remarkable ability to sequester or partition from the biota such metals as mercury and cadmium and such organics as chlorinated pesticides, polychlorinated biphenyls, and polynuclear aromatic hydrocarbons is attributable to the clays, humic acids, and hydrous oxides of iron and manganese that most estuarine sediments possess. As will be explained more fully later, the strength of this binding capability is dependent upon the development of reducing conditions, such as occur in a mound of material on the seabed.

It is advised that environmental managers in a Federal or state agency should never prescribe a disposal option without understanding the effect of the receiving environment upon the toxicant-sequestering properties of the dredged material. Realizing that the technical factors involved are often poorly understood by some environmental managers and not at all by the public, the decision was made to include a brief discussion of the most important of these physicochemical factors in this guide.

BIOAVAILABILITY AS A DETERMINANT OF MARINE SEDIMENT COMPONENTS

The Significance of Bioavailability

Bioavailability in environmental terms simply means how much of a given toxicant contained in a complex mixture such as dredged material is actually available to harm the biota. Although a bulk analysis of a particular dredged material taken from a harbor may reveal the presence of a toxicant, it may be bound so effectively by a component of the dredged material that it is unavailable to the biota. In other words, it is simply not bioavailable. This is tantamount to saying that the toxicant cannot exhibit toxicity, persistence, or bioaccumulative potential. To understand this capability of estuarine sediments, we must examine the sequestering properties of certain clay minerals, humic acids, sulfides and, to a lesser extent, certain metal hydroxides. The objective here will be to provide enough of the fundamental science to explain how a clay micelle can bind a toxicant, rendering it unavailable, and at the same time reveal the prodigious numbers of cations of a toxic metal, say mercury, that a single clay micelle of the appropriate type can take out of circulation and thus render harmless.

The Nature of Clays and Clay Minerals

The word "clay" can be applied to a variety of substances that differ rather widely in their mineralogical and chemical compositions. The term also has a geological connotation, referring to the small size of particles in a sediment bed. Generally, the principal size categories are sand, silt, and clay. But one should be aware that some clay particles may be of sufficient size to pass as silts. True silts, however, are primarily quartz derivatives that do not have the sequestering properties that we wish to discuss here. Therefore, when the word clay is used in this appendix it will refer to the minerals of which clays are composed. It is these minerals that have the properties of importance in the determination of bioavailability. Basically there are two groups of clays: the silicate clays, which are predominant in temperate regions, and the iron and aluminum hydrous oxide clays, which are found in the tropics and semitropics (Buckman and Brady 1969). The principal focus of our examination will be upon the silicates, because they predominate in developed agricultural regions of the world which, in turn, are often adjacent to rivers that drain into estuaries and harbors that from time to time will require maintenance dredging.

Structural characteristics of clays

In addition to their chemical composition, clays are characterized by the small size of their particles, which are never more than $2\ \mu$ in diameter (they range to $0.01\ \mu$), by their great number of particles or micelles per gram of clay, and by the huge total surface area of the particles in only a gram of clay (Tables A1 and A2).

Table A1
Size and Surface Area of Sediment Separates

<u>Separate</u>	<u>Diameter mm</u>	<u>Number of Particles per Gram</u>	<u>Surface Area of 1 g of Soil, m²</u>
Coarse sand	2.00-0.200	720	0.0023
Fine sand	0.20-0.020	46,000	0.0091
Silt	0.02-0.002	5,776,000	0.0454
Clay	Below 0.002	90,260,853,000	47.0000

The exceedingly large surface areas of some clays (Table A2) is attributed to the fact that their micelles are layered or laminated. Thus, as we shall see, the surface area of the micelles in a single gram of colloidal clay is huge, not only because of their small size, but also because of the surfaces on their internal crystal lattice.

Table A2
Total Surface Area of Sediment Components per Gram

<u>Component</u>	<u>Surface Area, m²/gram</u>		
	<u>External</u>	<u>Internal</u>	<u>Total</u>
Coarse sands	0.0023	0.00	0.0023
Fine sands	0.0091	0.00	0.0091
Silts	0.0454	0.00	0.0454
Some clays	47.0000	753.00	800.0000

It is the smectites (of which montmorillonite is an example) and the vermiculites that have micelles with the largest internal surface area. It is these surfaces, which invariably bear negative charges, that attract and hold cations (positive ions) of the toxic metals and organochlorine substances. Some understanding of the huge number of charges that a single montmorillonite clay micelle can possess may be obtained by noting that the area required for one charge is only 1.36 billionths of a square meter out of the total of 800 m² of a single gram of laminated micelles (Greenland and Mott 1978). The fact that surfaces of clay particles are so extensive and reactive demonstrates why surface chemistry controls the behavior of dredged materials. Hence, it is impossible to understand dredged material properties in regard to pollutant sequestration without some knowledge of the nature and extent of the surfaces of the clay minerals.

Major types of silicate clays

There are three principal groups of silicate clays--the kaolinites, the smectites, and the hydrous micas of which illite is representative. In addition, we shall recognize vermiculite, which does not fit easily into any of the above groups, as a separate entity, although it does exhibit some properties of the smectites.

Kaolinite group. Members of this group are aluminum silicates. Although there are several clays in the group, kaolinite is of greatest importance in soils and thus in sediments that are dredged. In fact, kaolinite is one of the most widespread clay minerals in soils (Dixon 1977). The crystals or micelles of this mineral are platelike in nature, being built up of flat units. These units in turn are composed of alternate layers of octahedral alumina and tetrahedral silica sheets. The two sheets of each crystal unit are held together by oxygen atoms that are shared by the silicon and aluminum atoms in their respective sheets. Since every unit contains one each of silica and aluminum sheets, this group of clays is said to have a 1:1 type of crystal lattice (Buckman and Brady 1969). The units are held together rather tightly by some oxygen-hydroxyl linkages so that no expansion occurs between units when the clay is wetted. Because of this, cations and water cannot enter between the structural units of the micelle. This means that its effective surface area for binding cations of toxicants is virtually restricted to the relatively small external surface of the micelle.

Kaolinite is common in the marine sediments of the Atlantic Ocean from South America to Africa, and in the Indian Ocean and the western Pacific Ocean.

Smectite group. The smectite group includes some of the most important clay minerals in sediments. The smectites, including all of the minerals formerly classified in the montmorillonite group of expansible-layer silicates, are aluminum silicates (Borchardt 1977). Three smectites, viz., montmorillonite, beidellite, and nontronite, are important in sediments, but we shall restrict our study primarily to montmorillonite.

The micelles or crystals of montmorillonite are composed of two tetrahedral silica sheets with an octahedral alumina sheet bound in between by shared oxygen atoms. This is a 2:1 crystal lattice. The layers readily expand and contract with wetting and drying, allowing cations and water molecules to move inside the lattice. As a result, it has internal surfaces of far greater area than the external surface of the micelle. Accordingly, montmorillonite has a very high cation adsorption capacity, which is estimated to be about 15 times that of kaolinite (Buckman and Brady 1969).

Foth (1978) has pointed out the following property of montmorillonite that is germane to the present discussion. During its formation some of the aluminum atoms in the interstices of the octahedral layer are replaced by magnesium. This substitution of Al^{3+} by Mg^{2+} can occur because the two atoms are of similar size so that the replacement of about one sixth of the Al atoms does not cause excessive strain in the lattice. This substitution is called isomorphous substitution. But because of the difference in valences involved, each substitution, atom for atom, leaves the lattice with one unsatisfied negative charge. The charge is permanent and is satisfied by hydrated cations. But, as will be explained shortly, more of the cation adsorption capacity of montmorillonite arises from another source.

The smectites are widely distributed in soils and sediments around the world. Thus, montmorillonite is very prevalent among dredged materials and accounts for a great deal of the latter's toxicant sequestering capabilities.

Hydrous micas. This is the third principal group of clays, and illite is the most important member of the group. It is a potassium aluminum silicate, and has a 2:1 lattice like that of montmorillonite, but it differs from the latter in that its micelles are larger and about 15 percent of the silicon in the silica sheets has been replaced by aluminum. The sheets of the illite micelle do not expand readily; hence, its ability to adsorb cations is not as great as that of montmorillonite. Furthermore, the replacement of Si^{4+} by Al^{3+} should leave an unsatisfied negative charge, but it does not because most of the charge has been neutralized by potassium ions that sit in the hexagonal holes of the planar surface of the adjacent units. This potassium forms a bonding mechanism called a potassium bridge, which holds adjacent layers together and produces a nonexpanding lattice. However, some of the tetrahedral aluminum ions around the edges of the particles are not involved in forming potassium bridges and thus serve as cation exchange sites. But the cation adsorption capacity of illite is still only about one third as great as that of montmorillonite. During weathering of illite, however, if all or most of the potassium is removed from the interlayer positions, the clay becomes an expanding lattice type of clay called vermiculite.

Vermiculite. The recognition of vermiculite as an important component of soils and aquatic sediments is relatively recent. Vermiculite is very widely distributed over the world and has the most extensive size distribution, from fine clay through coarse sand, of any clay of importance to this discussion (Douglas 1977). Vermiculite is of importance because it has cation exchange capacities as great as or greater than those of montmorillonite. In fact, dioctahedral vermiculites have cation exchange capacities of over 200 milliequivalents (m.e.)/100 g. The term milliequivalent will be defined in a subsequent section of this appendix. Suffice it to say here that vermiculites and smectites have the highest milliequivalent ratings of any clay minerals in dredged material.

Material mixtures. Before moving forward to discuss the concept and application of cation exchange capacity (CEC), we must emphasize two important points. First, the specific clay groups discussed above do not occur independently of each other. Accordingly, in a given marine sediment suite one may well find several clay minerals in a well-mixed state. Moreover, minerals will often be found that have compositions intermediate between those of two well-defined minerals, e.g., illite-montmorillonite. Second, it is necessary to note that there are colloidal minerals or clays other than silicates. The most important of these are the hydrous oxides of iron, aluminum, and manganese. The iron oxides occur in almost all sediments, where they may cause some distinctive red or

yellow coloration. Furthermore, they have adsorption sites for various anions and cations, particularly those of importance in environmental pollution (Schwertmann and Taylor 1977). The manganese oxides and hydroxides have high CECs for heavy metals, and they may control the availability of certain trace elements that are essential to the biota (McKenzie 1977). Interestingly, manganese oxides have a special affinity for lead (Pb). Norrish (1975) has observed Pb at levels of 2 percent in accumulations of manganese oxides in marine sediment.

The relationship between particle size and kinds of minerals present is fairly constant. Quartz dominates in the sand and coarse silt fractions of sediment. Primary silicates such as feldspars and micas are present in sands but disappear in the clays. The secondary silicates that were just discussed above dominate in the clay fraction. Under the category of secondary minerals we find the oxides of iron and aluminum, which are found in sands, clays, and silts but are most abundant in the latter.

THE NATURE OF HUMUS

Chemical Composition

Another very important pollutant-sequestering component of soils, sediments, and dredged materials is the organic complex called humus. Humus is a heterogeneous mixture composed largely of products resulting from microbial and chemical transformations of organic debris. It has considerable resistance to further microbial attack when fully formed (Hayes and Swift 1978). Unlike the clay minerals where aluminum, silicon, oxygen, and iron are important structural elements, humus being of biological origin is composed principally of carbon, hydrogen, oxygen, and nitrogen. It is practically insoluble in water, but it does go into colloidal suspension in water. The major portion of the organic matter in most dredged sediments and waters consists of three main fractions:

- a. Fulvic acid, which is the lowest in molecular weight, is soluble in both dilute alkali and acid, and in water at near neutral pH.
- b. Humic acid, which is medium in molecular weight, is soluble in alkali but not in acid.
- c. Humin, which is highest in molecular weight, is not soluble in either alkali or acid.

Of central importance to the pollutant-binding capability of humus, which is large, is the fact that it contains carboxyl (COOH) and phenolic OH groups, the hydrogen of which can be replaced by other cations (Buckman and Brady 1969).

Structural Characteristics

Humus is highly colloidal, but unlike the clays it is not crystalline. Nevertheless, its colloidal particles may be referred to as micelles. These micelles essentially act as anions, which under the right conditions of pH attract swarms of cations both externally and internally. As a matter of fact, the surface area and adsorptive capacity of a humic micelle far exceed those exhibited by any of the clays. For instance, the cation exchange capacity of silicate clays may range from 8 to 150 m.e./1,200 g, whereas that of humus usually ranges between 150 and 300 m.e. The importance of this to pollutant sequestration in dredged material will be discussed in the next section. Suffice it to say here that the CEC of dredged material having only 1 percent humus would be about 2 m.e. per 100 g of dry

material. The comparable figure for clays would average about 0.5 m.e., which is only a quarter that of humus (Buckman and Brady 1969).

Humic substances are readily adsorbed on soil clay mineral and hydrous oxide surfaces. Surface adsorption may, in addition to metal complexing, also involve the formation of H-bonding between COOH, OH, and C=O groups in fulvic and humic acids and OH and O on minerals (Schnitzer and Kodama 1977). Humic and fulvic acids are strongly bound on the internal surface of smectites, especially montmorillonite, at pHs less than 5.0. These coatings on clays serve to adsorb organic pollutants.

Cation Exchange Capacity and Millequivalents

Definitions and relationships

Cation exchange capacity (CEC) is defined as the sum total of exchangeable cations that sediment particles can adsorb per unit of dry weight of soil or dredged material (Buckman and Brady 1969). Its value is expressed in milliequivalents per 100 g of dry sediment or sediment components. Milliequivalent is defined as 1 mg of H⁺ or the amount of any other ion that will combine with or displace it. For instance, if a dredged material had a CEC of 10 m.e., it would be capable of adsorbing and holding 10 mg of H⁺ or its equivalent for every 100 g of dry dredged material. This is 10 mg to 10⁵ mg of dredged material or 100 ppm. So, 2×10^6 kg of dredged material could adsorb 200 kg of exchangeable H⁺ or its equivalent. To convert this to, say, cadmium, simply multiply the hydrogen value by the ratio of the atomic weight over the valence of the other metal.

The molecular interactions that govern adsorption processes, which of course are the basis of CEC, are fundamentally the same as those that determine the properties of matter in general (Burchill, Hayes, and Greenland 1981). That is to say, they are electromagnetic in character, and are essentially electrostatic and involve the coulombic interactions between nuclei and electrons.

The micelles of silicate clays and of humus, as we have seen, carry a net negative charge. As a consequence, literally swarms of cations are attracted to and, in some cases, into each micelle. The micelle, then, is acting much as an anion whose surfaces have a highly electronegative character. It must be recalled that the clay micelles are made up of a stack of plate-like structural units that in the case of a mineral such as montmorillonite can expand revealing very large internal surfaces available for adsorption of cations.

Sources of the negative charge

Silicate clays. The smectites, vermiculites, hydrous oxides, and micas are the most important of the inorganic constituents which contribute to cation exchange in sediments (Talibudeen 1981). There are two important phenomena that account for the negative charges associated with silicate clay micelles. The first involves unsatisfied valences at the broken edges of the silica and alumina sheets where one finds oxygen and hydroxyl groups which act as exchange sites. At pHs above 7.0 the H⁺ of the OH radicals dissociates slightly, and the micelle surface is left with a negative charge carried by the oxygen. This loosely held hydrogen is readily exchangeable. This exchange process is termed pH-dependent, because the charge is low in slightly acid conditions and increases as the pH rises. Favorable conditions for facilitating increased pH-dependent exchange with toxic cations are created in sediments on the seafloor from which they are dredged

and onto which they are disposed (pH of seawater is about 8.0 to 8.2). On the other hand, upland disposal above the water table promotes a lowering of pH because any sulfides present are readily oxidized to sulfate as drying proceeds with the ultimate production of weak sulfuric acid. The CEC of the disposed sediments is then reduced drastically, and, indeed, toxic metal and other cations are liberated to find their way into streams or ground-water aquifers.

The second and more important way that negative charges are produced on silicate clay micelles is by ion substitution, which is usually referred to as isomorphous substitution. For example, in montmorillonite and other 2:1 layered silicates, most of the CEC arises from the substitution of Mg^{2+} , Al^{3+} , or Si^{4+} in the octahedral and tetrahedral sheets by isomorphous ions of smaller valency, e.g., Li^{+} , Fe^{2+} and Al^{3+} (Talibudeen 1981). This leaves an unbalanced negative charge at the site. In waters rich in Na^{+} ions, the interlayer space of a smectite expands to almost complete separation of the layers so that the toxic ions have easy and complete access to negatively charged sites. For this reason the total negative charge calculated from isomorphous substitution equals the potential CEC (Farmer 1978). This process is independent of pH.

Humus. As noted previously, humus has a colloidal organization not unlike that of clays, i.e., it has a highly charged micelle that is surrounded by a swarm of cations. However, the CEC of humus may be as much as 4 times that of montmorillonite or even vermiculite. The major sources of the negative charge of the humus micelle are the carboxyl groups and the phenolic hydroxyl functional groups. The H^{+} of these groups is partially replaced by other cations. Under strongly acid conditions, H^{+} is tightly bound and not replaceable. Under weakly alkaline to alkaline conditions the H^{+} on both carboxyl and phenolic hydroxyl groups ionizes and is replaced by other cations. Humics are highly efficient at combining strongly with a large number of heavy metal cations (Hayes and Swift 1978). Note also that the CEC of humus is almost entirely pH dependent.

Surface areas available for ion exchange. It is well at this juncture to review the facts about the surface areas of the clay mineral and humus colloidal particles. As noted earlier, these surfaces have astoundingly large areas. Clays in general have a cumulative particle external area of about 47 m^2 for every gram of dry weight. Smectites and other components have even larger external surface areas. But the internal surface area of montmorillonite is about 16 times that of the external part of the micelle, reaching about 753 m^2 per gram of dry clay. Thus, the total area of which much is available for adsorption is 800 m^2 or 8 percent of a hectare per single gram. This area can probably accommodate on the order of at least a trillion sites to attract a huge number of cations (Greenland and Mott 1978). This number is obviously affected by the size of the atoms and their valence.

In this study let us consider atoms to be fully ionized, solid spheres of constant radius. Moreover, it is convenient to accept the concept of Brown and Parsons (1978) that these ions will take up the arrangement in the lattice space of the micelle that will minimize the electrostatic potential. The relative sizes of some common sediment cations and anions are tabulated in Table A3.

Table A3
Sizes of Common Cations and Anions
(in Nanometers)

Si	= 0.041	Fe2+	= 0.075
Al	= 0.050	Na	= 0.098
Fe3+	= 0.060	Ca	= 0.099
Cr	= 0.064	K	= 0.133
Mg	= 0.065	F	= 0.136
Zn	= 0.074	OH	= 0.130
Li	= 0.078	O	= 0.140

We see that in general cations are smaller than anions. The efficiency with which ions will replace each other is determined primarily by the following three factors:

- a. Relative concentrations, conforming to mass action of ions.
- b. The number of charges on the ions, conforming to valence.
- c. The activity of mobility of the ions, which is determined by size and hydration of the ion.

Factor a is simply an expression of the Law of Mass Action. Factor b is straightforward in that most monovalent ions are easily replaced by ions of higher valence. It is therefore important to note that most of the toxic metals of concern in ocean dumping, e.g., Hg, Cd, As, and Pb, have valences of 2 or more, so they tend to replace Na ions and are bound tightly. Because of physical constraints, hydrated ions whose size is thus increased cannot get as close to the micelle as other ions; hence, they are rather easily displaced or "exchanged." Thus, even though the Li ion is smaller than either Na or K ions, it is readily replaced because its extreme hydration increases its effective size and thus weakens its binding. Of interest to the process of disposal of dredged material into the ocean is the fact that the Na ion, which is abundant in seawater, is more highly hydrated than the K ion.

Application of CEC values to computations involving dredged material

A rough estimate of the capacity of marine sediments to adsorb pollutants can be calculated if one knows the relative clay mineral and humus composition of the dredged material in question. As stated earlier, CEC indicates the number of cations adsorbed, computed in milliequivalents per 100 g of dry sediment. Since a milliequivalent denotes 1 mg of hydrogen or the amount of any other ion that will displace it, an equivalent weight is that quantity that is chemically equal to 1 g of hydrogen. From elementary chemistry it will be recalled that the number of hydrogen atoms in an equivalent weight would be Avogadro's number 6.02×10^{23} . Hence, an amount of dredged material having 1 m.e. of CEC would have to contain $\frac{6.02 \times 10^{23}}{1,000} = 6.02 \times 10^{20}$ negatively charged adsorption sites.

Doubtless the CEC of typical dredged material will be many times the 1 m.e. used in the above calculations. The total CEC of the dredged material is the total number of

exchange sites of the organic plus the mineral colloids. Without going into great detail, we may assume that the following CECs are within reason:

Organic matter	--	200 m.e./100g dry sediment
Montmorillonite	--	100 m.e./100 g dry sediment
Illite	--	30 m.e./100 g dry sediment
Kaolinite	--	8 m.e./100 g dry sediment

Quite possibly the average CEC of the mixture of the various clay minerals might be about 50 m.e./100 g dry sediment. Accordingly, the CEC of the dredged material (ignoring some of the lesser values for silt and sand) can be calculated as follows:

CEC of 100 g of dredged material will have 2 m.e. for each 1% of organic matter (humus) and 0.5 m.e. for 1% of clay minerals.

Therefore, a dredged material with 10 percent humus and 46 percent clays would have a CEC of 43 m.e. per 100 g ($2 \times 10 + 0.5 \times 46 = 20 + 23 = 43$) m.e./kg.

On this basis consider the number of negatively charged adsorption sites that there will be in a cubic meter of this particular dredged material. A cubic meter of this material could easily weigh 1,300 kg. Hence, 1,000 m³ of the material, weighing some 1,300,000 kg, could adsorb 13 kg of exchangeable H⁺ or its equivalent. Let us see what this would mean in terms of Cd or Hg, which have atomic weights of 112 and 200, respectively. Both Cd and Hg are divalent, so each is equal to 2 H⁺. Therefore, it would take $11\frac{1}{2}$ or 56 mg of Cd or $200\frac{1}{2}$ or 100 mg of Hg to displace 1 mg of H. Accordingly, every 1,000 m³ of this dredged material could adsorb 728 kg of Cd or 1,300 kg of Hg or some combination of the two and sequester it from the biota in the reducing environment of the mound on the seabed.

Relationships among CEC, toxic metals, and soils

In an excellent review of metals in soils and sewage sludges by Logan and Chaney (1983), one finds a reinforcement of the importance of cation adsorption as a process for sequestering toxic cations. Page (1974), after an extensive review of the subject, concluded that sorption reactions predominated in tying up metal ions experimentally added to sediments and soils. The CAST Report (1980) also concluded that adsorption and CEC are the predominant mechanisms by which trace metals are removed from dilute solutions by clay minerals, metal oxides, and humus, as well as by whole soils or sediment. Just as with animals, Chaney (1973) concluded that pH, CEC, and humus content of the sediments controlled metal toxicity to plants. He also pointed out that CEC was important in binding all cations, and a sediment with high pH is a better binder of toxic metals than one with a low pH (acid).

Of great importance to an understanding of the low risk of disposing of dredged material containing toxic metals on the ocean floor is the fact that the literature reviewed by the present authors and Logan and Chaney (1983) consistently identified pH of the soil and/or sediments as controlling metal availability. Low pH, as we have seen, lowers the adsorption of metals to pH-dependent, specific adsorption sites on mineral surfaces, because H⁺ is a competitive cation, and also lowers the CEC of humus which exhibits a largely pH-dependent cation-binding characteristic.

CEC and the upland versus ocean disposal debate

A debate of long standing continues as to whether the ocean can provide a safe alternative to upland disposal of dredged material. In the present discussion, economic factors are not taken into consideration even though they are important and are referred to in the 1977 Regulations and Criteria. It is only fair to say that some nations strongly support the position that would ban the dumping of all wastes into the ocean. To support such an extreme position, considering the fact that the oceans cover 70 percent or so of earth's surface, appears to ignore the existence of major differences among wastes, and seems to fly in the face of scientific and technical data that point to some of the dangers of land disposal. In view of this, it seems fair to support the contraposition in regard to dredged material by drawing a straightforward comparison between the impacts that develop when a cadmium-containing dredged material is disposed of in the ocean and in an upland site.

As Patrick, Gamrell, and Khalid (1977) have pointed out, when anaerobic dredged sediment disposal is accomplished by deposition with diked structures on land, extensive oxidation of organic and inorganic dredged components will occur as the material continues to drain and dry. In those sediments containing appreciable quantities of sulfide, oxidation of the sulfide to sulfate in a surface oxidized layer (which slowly increases in depth with time) will result in the formation of a weak sulfuric acid solution. This weak acid will not only affect the surface oxidized layer but can leach into subsurface reduced horizons. As a result, the pH will drop and the redox will rise (become oxidizing) and desorption of metal ions and those of other compounds from the clay minerals will occur. As a result of these and other observations, Patrick, Gambrell, and Khalid (1977) concluded that upland disposal would accentuate release of metal ions and organic compounds bound to clay minerals and humus. We have summarized our position in regard to this issue in Table A4.

Table A4
Fate of Cadmium Bound to Clay Minerals
Under Seafloor and Upland Disposal

Mound of Dredged Material at Seafloor Site	Dredged Material in Upland Diked Containment Site
1. Low redox maintained (reducing)	1. Redox increases
2. Sulfide persists	2. Sulfate produced
3. Acid not produced	3. Weak acid formed
4. pH remains above 6.5 (neutral)	4. pH drops to near 3.0 (acid)
5. Cd remains immobilized (bound)	5. Cd mobilized (migrates)
6. Cd not bioavailable	6. Cd now bioavailable
7. Leaching insignificant	7. Leaching potential high
8. Safe disposal alternative	8. Dangers to aquifer and receiving waters

There can be no doubt that upland disposal in the case cited above should not be the alternative of choice taken by any reasonable and knowledgeable manager. In this example we see the very real danger of contaminating ground-water supplies, which may take decades to purify even after disposal ends.

REFERENCES

- Borchardt, G.A. 1977. Montmorillonite and other smectite minerals. In J. Dixon and S.B. Weed (eds.), *Minerals in Soil Environments*. Soil Sci. Soc. of Amer., Madison, WI.
- Brown, D.A., and T.R. Parsons. 1978. Relationship between cytoplasmic distribution and toxic effects to zooplankton and chum salmon exposed to mercury in a controlled ecosystem. *J. Fish. Res. Board Canada* 35:880-884.
- Buckman, H.O., and N.C. Brady. 1969. *The nature and properties of soils*. The MacMillan Company, London.
- Burchill, S., M.H.B. Hayes, and D.J. Greenland. 1981. Adsorption. In D.J. Greenland and M.H.B. Hayes (eds.), *The Chemistry of Oil Processes*. John Wiley and Sons, New York.
- CAST Report. 1980. Effects of sewage sludge on the cadmium and zinc content of crops. Council for Agri. Sci. and Tech., No. 83, Ames, IA.
- Chaney, R.L. 1973. Crop and food chain effects of toxic elements in sludges and effluents. In *Recycling Municipal Sludges and Effluents on Land*. Nat. Assoc. State Univ. and Land Grant Colleges, Washington, DC.
- Dixon, J.B. 1977. Kaolinite and serpentine group minerals. In J.B. Dixon and S.B. Weed (eds.), *Minerals in Soil Environments*. Soil Sci. Soc. of Amer., Madison, WI.
- Douglas, L.A. 1977. Vermiculites. In J.B. Dixon and S.B. Weed (eds.), *Minerals in Soil Environments*. Soil Sci. Soc. of Amer., Madison, WI.
- Farmer, V.C. 1978. Water on particle surfaces. In D.J. Greenland and M.B.H. Hayes (eds.), *The Chemistry of Soil Constituents*. John Wiley and Sons, New York.
- Foth, H.D. 1978. *Fundamentals of soil science*. John Wiley and Sons, New York.
- Greenland, D.J., and C.J.B. Mott. 1978. Surfaces of soil particles. In D.J. Greenland and M.B.H. Hayes (eds.), *The Chemistry of Soil Constituents*. John Wiley and Sons, New York.
- Hayes, M.B.H., and R.S. Swift. 1978. The chemistry of soil organic colloids. In D.J. Greenland and M.B.H. Hayes (eds.), *The Chemistry of Soil Constituents*. John Wiley and Sons, New York.
- Logan, T.J., and R.L. Chaney. 1983. Utilization of municipal wastewater on land--metals. In A.L. Page, T.L. Gleason, J.E. Smith, I.K. Iskandar, and L.E. Sommers (eds.), *Utilization of Municipal Wastewater and Sludge on Land*. Procs. of the 1983 Workshop, Univ. of Calif., Riverside, CA.
- McKenzie, R.M. 1977. Manganese oxides and hydroxides. In J.B. Dixon and S.B. Weed (eds.), *Minerals in Soil Environments*. Soil Sci. Soc. of Amer., Madison, WI.
- Norrish, K. 1975. Geochemistry and numerology of trace elements. In D.J. Nicholas and A.R. Egan (eds.), *Trace Elements in Soil-Plant-Animal Systems*, Academic Press, New York.

- Page, A.L. 1974. Fate and effects of trace elements in sewage sludge when applied to agricultural lands. A literature review study. EPA/601/2-7A/005, US Environmental Protection Agency, Washington, DC.
- Patrick, W.H., R.P. Gambrell, and R H. Khalid. 1977. Physiochemical factors regulating solubility and bioavailability of toxic heavy metals in contaminated dredged sediment. *J. Environ. Sci.* A12(9):475-492.
- Schnitzer, M., and H. Kodama. 1977. Reactions of minerals with soil humic substances. In J.B. Dixon and S.B. Weed (eds.), *Minerals in Soil Environments*. Soil Sci. Soc. of Amer., Madison, WI.
- Schwertmann, U., and R.M. Taylor. 1977. Iron oxides. In J.B. Dixon and S.B. Weed (eds.), *Minerals in Soil Environments*. Soil Sci. Soc. of Amer., Madison, WI.
- Talibudeen, O. 1981. Cation exchange in soils. In D.J. Greenland and M.B.H. Hayes (eds.), *The Chemistry of Soil Processes*. John Wiley and Sons, New York.

APPENDIX B: FACTORS REDUCING ADVERSE EFFECTS OF TOXIC SUBSTANCES IN DREDGED SEDIMENTS

Note: In addition to the chemical properties of dredged material that reduce or eliminate the bioavailability of possible contaminants, there are physical factors that determine the degree of sequestration. Brief descriptions of these factors are discussed in this appendix, along with important properties of some of the most serious contaminants that may be found in marine sediments.

FACTORS REDUCING ADVERSE EFFECTS OF TOXIC SUBSTANCES IN DREDGED SEDIMENTS

GENERAL

In addition to the properties of some clays and humus that sequester toxic substances in dredged materials, there are several other physicochemical factors that strongly influence the interaction between dredged material and contaminants. We are concerned here primarily with the pollutants listed in Annex I (the "black list") and Annex II (the "grey list") of the London Dumping Convention. The Annex I substance categories are chlorinated hydrocarbons (e.g., PCBs and DDT and derivatives); mercury (Hg) and mercury compounds, especially methyl mercury; cadmium (Cd) and cadmium compounds; and certain petroleum hydrocarbons, especially the polynuclear aromatic hydrocarbons (PAHs). Among the principal Annex II substances are arsenic (As), lead (Pb), zinc (Zn), chromium (Cr), and organophosphorus and carbonate pesticides. The ensuing paragraphs will be devoted to (a) descriptions of the chemical processes affecting the mobilization or immobilization of metals and other contaminants in sediments and (b) discussions of some properties of the toxicants listed above. As we shall see, Hg, Cd, Pb, Cu, Zn, and As are metals of major concern in ocean dumping regulations because of their toxic effects and tendency to bioaccumulate in marine organisms. The impact of such compounds as tributyltin, dibutyltin, and monobutyltin in dredged material has not been thoroughly evaluated. We do know, however, that these substances are bound by clay micelles.

CHEMICAL FACTORS AFFECTING BIOAVAILABILITY

Redox Potential and Acid-Base Reaction

One of the most important properties of marine sediments and thus dredged materials that controls the behavior of pollutants is its oxidation-reduction or redox condition (Eh). Redox potentials of +500 mv or higher represent oxidizing conditions, whereas redox potentials of -250 mv or lower represent very reducing conditions. The fixation of potentially toxic substances in dredged material, as well as their release, will be affected by the redox status of the material after disposal. For example, metals bound by sulfide in low redox conditions (reducing) will be mobilized to some extent if the sediment is placed into a high redox environment where sulfide is oxidized to sulfate. The escape of the metal ions may not be complete, however, because those released by sulfide may then be immobilized by reactions with iron oxides. Eh and pH are closely associated in these reactions. A pH of 7.0 is neutral, whereas pH values below 7.00 are acid and those above are alkaline.

Typical marine surface waters are generally saturated or nearly so with dissolved oxygen, ranging in Eh from about +300 to +600 mv, and in pH from about 5.0 to 8.5. Sediments, however, diverge sharply from these conditions of the water column. The Eh in sediments may range from moderately to strongly reducing (-100 to -400 mv), while pH tends to be near 7.0 (neutral). These conditions of neutral or slightly alkaline pH and anaerobic or reducing Eh, which are found in most dredged sediments, will definitely reduce the availability of toxic metals. When dredged materials are deposited on the seafloor, these conditions that promote immobilization of toxicants are maintained. On the other hand, upland disposal will more likely favor aerobic redox and acid pH, which are

conditions that promote increased mobilization and thus bioavailability of toxic metals. Failure to take these matters into consideration has led to overregulation of the dredging-disposal process in some regions of the United States, which in turn has resulted in unnecessary litigation and sometimes economic hardships.

Cation Exchange Capacity

Although cation exchange capacity (CEC) is discussed more fully in Appendix A, it is emphasized that the net negative charge that is a property of clays permits their surfaces to adsorb all positively charged ions (cations). Also, this adsorption is favored by low Eh and neutral pH which, as we have seen, are generally characteristic of mounds of dredged material lying on the seafloor. Humic acids also have a net surficial negative charge similar to that of clays, so that positively charged metal cations are adsorbed in exchangeable states at negative charge sites. Humic acids are also able to complex cations in more permanent bondings that result in insolubility, reduced reactivity, and reduced bioavailability.

Salinity

Salinity of dredged material has effects on the flocculation of the material and on the actions of the metal contaminants it contains. Clay and humic particulates are flocculated when they come in contact with saline or higher saline waters. The sodium ion in seawater has a specific effect of displacing other cations from the complex on colloids. This, however, will not occur to any appreciable extent if the sediments are dredged in saline (such as estuaries) waters and disposed in saline waters (such as the ocean).

OTHER FACTORS AFFECTING IMPACTS

Mixing and Dilution Effects

Typically when Annex I or any other toxicants are present in marine sediments their distribution pattern is not uniform on either the horizontal or vertical axis. If the toxicants are of anthropogenic origin, they can be more concentrated in the top or surficial layer of the sediment bed and near the source of the contaminants, be it a point source such as an effluent discharge pipe or aerosol discharges from a causeway. When these sediments are dredged and placed in the bins of a hopper dredge or the hold of a barge, they will be mixed so that any toxicants will be diluted and their concentrations possibly reduced to trace amounts in the mixture.

Enhancement of Sequestration Through Use of Special Care Measures

For the most part, such special care measures as capping either on level bottoms or in subaqueous pits increase the degree of effectiveness of those physicochemical parameters discussed above. Covering an already anaerobic mound of polluted dredged material with a thick layer of "clean" sediments will not only hold the mound in place but will ensure that the conditions of low redox and neutral or slightly alkaline pH will remain for long periods of time.

Some Properties of Annex I and Annex II Substances

Annex I - chlorinated hydrocarbons

General. Chlorinated hydrocarbons of concern in dredged material are polychlorinated biphenyls (PCBs) and various chlorinated pesticides, such as DDT, DDE, aldrin, and chlordane. Even where manufacturing of the parent compounds has been stopped, some sediments will remain contaminated for years to come. The Aroclors (PCBs) exhibit lipophilic and hydrophobic properties in aqueous environments, resulting in their ultimate accumulation in lipid layers of biota. In such depots, they have little effect on the metabolism of the host.

Toxicity. Although most organochlorines tend to be chemically inert and not very soluble in seawater, they can be very toxic. The USEPA water quality criterion for protection of marine life is 0.001 µg/L (ppb) some 50 times lower than for mercury. Some organochlorines are biodegradable, but the rate is slow in those having chlorine numbers over 4.

Chlorinated hydrocarbons in dredged material. There is no doubt but that marine organisms can bioaccumulate these compounds from water sources. But with the exception of very highly contaminated sediments, benthic organisms live normal life cycles, indicating only minor amounts of accumulation. This lack of bioavailability is explained in part by the fact that chlorinated hydrocarbons are strongly adsorbed on clay and other particulates (Burks and Engler 1978).

Annex I - mercury and mercury compounds

Mercury is considered to be one of the most hazardous of the heavy metals (Gambrell, Khalid, and Patrick 1978). It is remarkable that given its high toxicity there is little information on actual effects of mercury on natural populations of marine animals. This seems to be true of San Francisco Bay, where mercury has been only sporadically identified in a few aquatic species despite the history of mercury mining in the watershed, the nearby abundance of large cinnabar deposits, and a range of from 0.30 to 0.87 ppm Hg in the Bay sediments (Bradford and Luoma 1980).

The toxicity of mercury is related to the chemical form involved. The USEPA criterion for protection of marine life is 0.05 ppb Hg in water. We note, however, that the mercurous salts are less soluble than mercuric and consequently are less toxic, whereas the alkyl forms are most toxic in spite of the fact that methyl, dimethyl, and ethyl mercury are produced by microorganisms.

Although direct uptake of inorganic mercury from sediments may occur in benthic organisms, uptake of dissolved mercury from water seems much more likely. For instance, Fujiki, Hirota, and Yamaguchi (1977) found that organisms accumulated little methylmercury from spiked food sources and none from association with Minimata Bay sediments having concentrations of up to 600 ppm Hg. They concluded that any methylmercury accumulated by organisms in the Bay was derived from water.

An important aspect of the concept of bioavailability related to how much if any of the toxicant burden is given up by sediments during the dredging-disposal process and while the dredged material is in place. Obviously, organisms cannot accumulate or be affected by mercury that is strongly bound by the solids. Brannon, Smith, and Plumb (1978)

conducted elutriate tests on 32 sediments, representing a wide range of properties and pollution conditions, and found no ecologically significant releases from most sediments. It was concluded also that mercury exhibited the strongest affinity for sediments among the important toxic metals. Gambrell, Khalid, and Patrick (1978) found that sediment-bound mercury was not released to the water from the solid phase. Serne and Mercer (1975) found that humic materials in marine sediments strongly bind mercury, as do sulfide and various hydrous oxides (Gambrell, Khalid, and Patrick 1978).

Methylmercury is more mobile and readily accumulated by many organisms and is toxic in lower concentrations than inorganic mercury. There is evidence that the formation of methylmercury is minimized in sediments containing sulfides and displaying reducing conditions, as in a mound of dredged material on the seafloor.

Annex I - cadmium and cadmium compounds

General. Cadmium, which occurs in nature chiefly as a sulfide salt, is potentially a very hazardous pollutant in the environment and tends to be more easily taken up and concentrated by the biota than other metals. Its bioavailability in dredged material is reduced by low redox and neutral pH normally found in a mound of dredged material on the seafloor. Upland disposal of cadmium-bearing sediments is not advised because oxidizing conditions and acid pH mobilize the metal from the sediments.

Toxicity. The USEPA criterion for cadmium designed to give ample protection to marine life is 5.00 ppb, somewhat higher than the criteria for PCBs and Hg and considerably lower than that for Pb. Most 96-hr LC₅₀ tests for marine animals require concentrations of Cd as high as 320 to 420 ppb. Cadmium is taken up by various seagrasses and such crop plants as carrots, onions, wheat, and some leafy vegetables (Salomons and Kerdijk 1982).

Cadmium in dredged materials. Based on the laboratory tests of Ayling (1974), Chen et al. (1976), Wier and Walter (1976), Gambrell et al. (1977), and Neff, Foster, and Slowey (1978), it may be concluded that, under the usual conditions found in dredged material on the seabed, namely, nearly neutral pH and anaerobic redox, cadmium is effectively immobilized and quite unavailable to organisms. To the contrary, the reverse conditions that can easily develop at an upland disposal site increase the availability of cadmium to organisms and/or ground water many fold.

Annex I - petroleum hydrocarbons

General. Crude oils contain hundreds of thousands of different chemical compounds owing to complex molecular rearrangements resulting from processes involved in petroleum formation. The toxicity of these compounds varies widely. In laboratory tests, some of the aromatic petroleum hydrocarbons are very toxic, but in general those that are not volatile are very insoluble. Much of our concern about petroleum hydrocarbons is related to the publicity given to oil spills and the resulting impacts upon beaches and

birds. But recent evidence from the AMOCO *Cadiz*, which was the largest tanker spill in history (Gundlach et al. 1983)* and the IXTOC I, which was the largest production spill (Overton et al. 1980), reveals that although the initial impact in the *Cadiz* intertidal was severe, most of the obvious effects of the spill were gone in less than 3 years. One might have expected massive impacts upon the pelagic biota during IXTOC, but to date no evidence to that effect has been published.

Petroleum hydrocarbons consist of the following categories of compounds:

- a. Aliphatics, which are saturated open-chain compounds.
 - (1) Normal = n-alkanes.
 - (2) Branched or isoaliphatics or isoalkanes = pristane and phytane.
- b. Cycloalkanes, which are saturated ringed compounds such as naphthenes (e.g., cyclopentane and cyclohexane).
- c. Aromatic compounds, which consist of one benzene ring (e.g., benzene) or more (e.g., naphthalene with two rings and anthracene with three rings).

In addition, crude oils contain nonhydrocarbon constituents such as sulfur compounds, nitrogen compounds, porphyrins derived from chlorophyll, oxygen compounds (e.g., phenols and ketones), asphaltenes, and trace metals, particularly vanadium and nickel. The percentage composition of crude oil averages: normal and branched alkanes (30%), naphthenes (40%), aromatics (15%), and NSO compounds (5%)(Boehm 1981).

It is well known that hydrocarbons are synthesized by most marine plants and animals. Those produced are odd-numbered carbon chains, such as C₁₅-C₂₁ n-alkanes in phytoplankton. Pristane (C₁₉) is found in calanoid copepods and their fish predators. Terrestrial plants and *Sargassum* produce C₂₁ through C₃₃ odd chain n-alkanes with C₂₁-C₂₉ predominating in marsh grasses (Boehm 1981). Thus, marine biogenic hydrocarbons are usually odd chain n-alkanes in the C₁₅-C₁₇ and C₁₉ region, whereas land plant detritus is characterized by odd chain n-alkanes in the C₂₃ to C₃₃ range.

The ability to metabolize petroleum hydrocarbons is not limited to bacteria. Lee (1976) and Lee et al. (1979) cite some meiofaunal and macrofaunal organisms, among them harpacticoid copepods, nematodes, molluscs, crustaceans, and polychaete worms, which are able not only to metabolize petroleum hydrocarbons with a mixed-function oxidase system, but also to bring sediments up to the water-sediment interface where microbes will attack the oil on sediment particles. Sanders, Grassle, and Hampson (1972) noted that such opportunistic polychaetes as *Capitella capitata*, *Streblospio benedicti*, and *Polydora ciliata* are frequently associated with areas of high oil input. Hydrocarbon degrading organisms have been isolated from various types of marine sediments (Walker et al. 1976). After introduction of oil into sediments, there is a substantial increase in the populations of hydrocarbon-degrading microbes (Walker, Colwell, and Petrakis 1975). As a result of the metabolism of these organisms, the n-alkanes are rapidly degraded followed by slower

* The impacts of the Exxon *Valdez* have not been fully assessed at the time of this writing, but are expected to be extensive both in space and time.

action on isoalkanes, cycloalkanes, and aromatic hydrocarbons (Blumer, Ehrhardt, and Jones 1973; Lee 1976).

Toxicity. The toxicity of petroleum hydrocarbons depends upon the content of the soluble aromatic fraction, especially the multiringed aromatics which, being refractory to biodegradation, are likely to remain in sediments for protracted periods. The mono-aromatics are toxic, but acute toxicity increases with increasing molecular size up to 4- and 5-ring compounds. The impact of these is reduced, though, because of their very low water solubility. Thus, it appears that the most environmentally toxic compounds are the di- and tri-aromatic components. Anderson (1979) reported that refined products, such as No. 2 fuel oil, were generally more toxic than native crudes. Moreover, Anderson et al. (1977) found that organisms can tolerate much higher levels of oil mixed in sediments than they can in water extracts. Hence, the relative toxicity of PAHs is proportional to their solubility in water. There is mounting evidence that petroleum hydrocarbons in sediments have relatively low toxicity for marine organisms.

Petroleum in dredged material. Petroleum hydrocarbons in sediments appear not to represent a long-term threat to the quality of surface waters. This is because dredged material and other particulates, even suspended particulates in the water column, have a high affinity for petroleum components. In the case of the typical silt-clay textural dredged material derived from maintenance dredging projects, the petroleum hydrocarbons will be tightly bound to the solid phase. In most harbors the principal source of these compounds is from small boat operations so that phenanthrene and related compounds are the principal fractions in the harbor sediments. These compounds are readily degraded by microfauna and meiofauna. If levels remain high, it is not because of persistence, but because of the steady input from transport vessels. Release of petroleum hydrocarbons into the water column during dredging and dredged material disposal has been shown to be minimal in both laboratory and monitored disposal studies.

Annex II - arsenic

Four chemical species of arsenic exist in seawater and simple marine algae--arsenite, arsenate, dimethylarsinate, and methylarsinate (Andreae 1979). The biogeochemical cycle of arsenic in the surface ocean involves the absorption of arsenate by plankton, the conversion of arsenate to various organic compounds, and the release of arsenite and methylated species into the seawater. Organisms carry out dimethylation of the methylarsenicals and by so doing regenerate arsenates.

Toxicity. Trivalent inorganic arsenic is substantially more toxic than the pentavalent, but there is evidence that the trivalents are converted to the pentavalent forms in sediments. Johnston (1978) reported that methylated arsenicals tend to be less toxic than inorganic forms.

Arsenic in dredged materials. Brannon, Smith, and Plumb (1978) reported that arsenic had a very strong affinity for sediments, as determined by elutriate tests. However, it is known that arsenic release from sediments increases as pH increases, unlike the action of most toxic metals. Arsenite formation and stability are promoted by reducing conditions. Hence, because arsenite has greater toxicity and mobility than arsenate, and because both pH and redox are often favorable for arsenite formation in sediments, one must look for other agents that sequester arsenic in dredged material. Two such agents are iron and aluminum hydrous oxides, both of which are commonly found in dredged

material. As a result of their activities, subaqueous disposal of dredged material does not result in significant release of mobile arsenite which is formed in the low redox and neutral pH in a stable mound.

Annex II - zinc and chromium

General. Because their sediment chemistry, relative toxicities, and actions in dredged material are similar, it is appropriate to consider Zn and Cr together. Unlike Hg, Cd, Pb, and As, both Zn and Cr are essential metals to a wide range of animals, including man. Most benthic organisms can accumulate large amounts of Zn and/or Cr as compared with Hg and Cd without exhibiting toxic states. Chromium's concentration in seawater is remarkably low, being less than 1 ppb. Chromium deficiencies result in various metabolic dysfunctions related to glucose metabolism and growth. Zinc's concentration in seawater averages about 10 ppb. It occurs in nature as the sulfide and is essential for the formation of the prothetic group of several metabolic enzymes.

Toxicity. As might be surmised from its metabolic role, the threshold toxicity levels for Cr are comparatively high. Fish appear more tolerant of excess Cr levels than invertebrates. Whereas fish can tolerate levels of 200 ppm or more for protracted periods, invertebrates seldom have threshold toxicity levels in excess of 20 ppm. Threshold toxicity levels for Zn in marine animals are not well established. However, Neff, Foster, and Slowey (1978) found that levels as high as 276 ppm seemed to have little effect on test animals.

Zn and Cr in dredged materials. Hydrous oxides of iron and manganese are effective agents in immobilizing Zn and Cr under the low redox state in most stable dredged material mounds. This means that interstitial waters will have low values, resulting in curtailment of the aqueous avenue of metal absorption by the benthic biota.

Annex II - lead and its compounds

General. As far as is known, Pb is not an essential element in any metabolic process of plants or animals. Most of what we have learned about lead in the last few years indicates that, in marine ecosystems and especially in the sediments thereof, Pb is essentially innocuous. The accepted concentrations of Pb in open-ocean surface waters range between 5 and 15 ng Pb/kg and up to 50 ng/kg in highly polluted coastal waters (Burnett and Patterson 1980). The deeper waters of the oceans contain only 1 or 2 ng Pb/kg. The principal sources of Pb in marine waters and sediments are combustion of gasoline containing tetraethyl or tetramethyl lead and particulates carried in by rivers. Lead is tightly bound to particulates so long as the Eh is negative and the pH is near neutral. When so bound, it is unavailable to organisms and thus poses no environmental hazard.

Toxicity. The toxic effects of inorganic lead on marine animals are related to the chemical form in which the lead is present, i.e., ionic or particulate, and its solubility in the water. Lead has a very low solubility of about 0.003 mg/L in hard water and in seawater. In seawater it is present mainly as carbonate complexes, and the uncomplexed and most toxic species are present in extremely low concentrations. There have been few studies of the acute toxicity of inorganic lead to marine animals, primarily because of the difficulty of maintaining solutions of lead in seawater at concentrations high enough to cause toxic effects (Maddock and Taylor 1980). These authors noted that the 96-hr LC₅₀ values for

Pb in soft fresh water range between 1 and 10 mg/L and in saline waters between 300 and 500 mg/L.

Weis and Weis (1976, 1979) made a comparative study of the toxic effects of mercury, cadmium, lead salts, and methylmercury in solution on fin regeneration in killifish (*Fundulus heteroclitus*) and mullet (*Mugil cephalus*). The metal doses were as follows:

- Mercuric chloride - 0.01, 0.1, and 1.0 ppm
- Anhydrous cadmium chloride - 0.01, 0.1, and 1.0 ppm
- Lead nitrate - 0.01, 0.1, and 1.0 ppm
- Methylmercury - 0.001 and 0.01 ppm

Mercuric chloride at 0.1 ppm caused over 50 percent of the fish to die in 10 days or less, but fin regeneration was equal to controls at the time of death. The fish in Cd at all concentrations showed no healing of clipped fins nor any start of regeneration for days after it started in controls. Methylmercury produced significant retardation of growth in both species. It was found that Pb had no retarding effect on fin regeneration and was not otherwise toxic to either species at the concentrations used in the studies.

Lead in dredged material. Lead is known to occur in substantial amounts in contaminated sediments. Concentrations ranging from 50 to several hundred parts per million have been reported by Gambrell et al. (1977). However, lead is immobilized in most sediments and thus is not absorbable by organisms. Some studies have demonstrated small accumulations of Pb by benthos living in contaminated sediments, but the majority have not observed Pb uptake in ecologically significant amounts. In a study of the effects of pH and Eh on Pb release under simulated highly contaminated conditions, Gambrell et al. (1977) reported that soluble and exchangeable lead levels were undetectable by flame atomic absorption (less than 2 µg/g sediment basis) in Mobile Bay sediment-water system laced with 500 ppm Pb and incubated at pH 8.0 and low redox levels. However, 40 to 50 percent of the added Pb was recovered from the sediment samples incubated at pH 5.0 in soluble and exchangeable forms at the 500-ppm addition. In summary, we note that those properties of dredged material which favor sequestration of Pb are

- a. Fine textured clays.
- b. High organic content (humus).
- c. Low salinity.
- d. Strongly reducing redox.
- e. Presence of sulfides and hydrous oxides of iron and manganese.
- f. Near neutral pH.

Annex II - organophosphorus and carbonate pesticides

General. The organophosphorus insecticides are all structurally related and undergo similar reactions; hence, they will be discussed here as a group. Some of them are aliphatics, e.g., malathion, butonate, ethion, phorate, phosphamidon, and trichlorofen; others are aromatic derivatives, viz., parathion, diazinon, endothion, fenthion, and ronnel. Some of these compounds act directly on organisms, whereas others undergo oxidative conversions within the plant or animal before they kill. All are inhibitors of the enzyme

cholinesterase. The best known of these pesticides are parathion, methyl parathion, and malathion. Malathion has been more widely used because it possesses low toxicity for mammals, including man.

The best known of the carbamate insecticides is Sevin (carbaryl). This is also a cholinesterase inhibitor. Many of these pesticides have been transported widely throughout the world not only in food and water but also by air transport on dust and rain-out.

Toxicity. So far as mammals are concerned, it was found that malathion was least hazardous, while parathion and diazinon were among the most toxic. Some of the organophosphates are now known to cause acute toxicity to aquatic organisms.

A comparison of toxicities of common pesticides to mammals and birds shows that

- a. Parathion and methyl parathion are more toxic to mammals and birds than DDT, dieldrin, or carbaryl (Sevin).
- b. The least toxic to mammals are, in order, methoxychlor, malathion, and carbaryl, followed by DDT, dieldrin (more toxic than the parent compound DDT), methyl parathion, and parathion (the most toxic).
- c. The least toxic for birds appear to be, in order, DDT, carbaryl, methoxychlor, malathion, dieldrin, methyl parathion, and (most toxic) parathion.

Parathion is very toxic for marine fishes and invertebrates at concentrations around 10 ppb.

Organophosphates in dredged material. These pesticides ordinarily do not produce major environmental problems in dredged material for two reasons. First, sediment microorganisms metabolize the organophosphorus compounds fairly rapidly. Also, the higher the pH, the faster the rate of hydrolysis. Thus, it is unlikely that these compounds will remain for any protracted periods of time in dredged material. Second, the residues of the organophosphates tend to be bound very tightly to sediment particles, especially the clays. Even when organisms accumulate most of these pesticides in subacute concentrations, they are either metabolized or depurated through kidneys or gills.

REFERENCES

- Anderson, J.W. 1979. An assessment of knowledge concerning the fate and effects of petroleum hydrocarbons in the marine environment. Pages 3-21 in W.B. Vernberg, A. Calabrese, F.P. Thurberg, and F.J. Vernberg (eds.), *Marine Pollution: Functional Responses. Fate and Effects of Petroleum Hydrocarbons*. Academic Press, New York.
- Anderson, J.W., L.J. Moore, J.W. Blaylock, D.L. Woodruff, and S.L. Kieser. 1977. Bioavailability of sediment-sorted naphthalenes to the sipunculid worm, *Phascolosoma agassizii*. Pages 276-285 in D.A. Wolfe (ed.), *Fate and Effects of Petroleum in Marine Organisms and Ecosystems*. Pergamon Press, New York.
- Andreae, M.O. 1979. Arsenic speciation in seawater and interstitial waters: The influence of biological-chemical interactions on the chemistry of a trace-element. *Limnol. Oceanogr.* 24:440-452.
- Ayling, G.M. 1974. Uptake of cadmium, zinc, copper, lead and chromium in the Pacific oyster, *Crassostrea gigas*, grown in the Tamar River, Tasmania. *Water Res.* 8:729-738.
- Blumer, M., M. Ehrhardt, and J.H. Jones. 1973. The environmental fate of stranded crude oil. *Deep-Sea Res.* 20:239-259.
- Boehm, P.D. 1981. Petroleum in the marine environment. Physical/Chemical Methods. Background Paper. Workshop to update petroleum in the marine environment. NAS/NRC, Clearwater Beach, FL.
- Bradford, W.L., and S.N. Luoma. 1980. Some perspectives on heavy metal concentrations in shellfish and sediment in San Francisco Bay, California. Pages 501-531 in R.A. Baker (ed.), *Contaminants and Sediments*, Vol I.
- Brannon, J.M., I. Smith, and R.H. Plumb, Jr. 1978. The long-term release of contaminants from dredged material. Technical Report D-78-49. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Burks, S.A., and R.M. Engler. 1978. Water quality impacts of aquatic dredged material disposal. Technical Report DS-78-4. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Burnett, M., and C.C. Patterson. 1980. Analysis of natural and industrial lead in marine ecosystems. Pages 15-30 in M. Branica and Z. Konrad (eds.), *Lead in the Marine Environment*. Center for Marine Research, Ruder Boskovic Institute, Zagreb, Yugoslavia.
- Chen, K.Y., S.K. Gupta, A.Z. Sycip, J.C.S. Lu, M. Kezevic, and Won-Wook Choi. 1976. Research study on the effect of dispersion, settling, and resedimentation on migration of chemical constituents during open-water disposal of dredged materials. Contract Report D-76-1. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Fujiki, M., R. Hirota, and S. Yamaguchi. 1977. The mechanism of methylmercury accumulation in fish. Pages 89-95 in S.A. Peterson and K.K. Randolph (eds.),

- Management of bottom sediments containing toxic substances. EPA-600/3-77-083. Corvallis Environmental Research Laboratory, USEPA, Corvallis, OR.
- Gambrell, R.P., R.A. Khalid, and W.H. Patrick, Jr. 1978. Disposal alternatives for contaminated dredged material as a management tool to minimize adverse environmental effects. Technical Report DS-78-8. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Gambrell, R.P., R.A. Khalid, M.G. Verloo, and W.H. Patrick, Jr. 1977. Transformation of heavy metals and plant nutrients in dredged sediments affected by oxidation-reduction potential and pH; Vol II: Materials and methods/results and discussion. Contract Report D-77-4. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Gundlach, E.R., P.D. Boehm, M. Marchand, R.M. Atlas, D.M. Ward, and D.A. Wolfe. 1983. The fate of AMOCO *Cadiz* oil. *Sci.* 221:122-129.
- Johnston, S.W. 1978. The behavior of indigenous arsenic in flooded soils and sediments. M.S. thesis, Louisiana State University, Baton Rouge, LA.
- Lee, R.F. 1976. Metabolism of petroleum hydrocarbons in marine sediments. Pages 334-344 in *Proceedings of the Symposium--Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment*. Amer. Institute of Biol. Sciences, Washington, DC.
- Lee, R.F., S.C. Singer, K.R. Tenore, W.S. Gardner, and R.M. Philpot. 1979. Detoxification system in polychaete worms: Importance in the degradation of sediment hydrocarbons. Pages 23-37 in W.B. Vernberg, F.P. Thurberg, A. Calabrese, and F.J. Vernberg (eds.), *Pollution and Physiology of Marine Organisms*. Academic Press, New York.
- Maddock, B.G., and D. Taylor. 1980. The acute toxicity and bioaccumulation of some lead alkyl compounds in marine animals. Pages 233-261 in M. Branica and Z. Konrad (eds.), *Lead in the Marine Environment*. Center for Marine Research, Ruder Boskovic Institute, Zagreb, Yugoslavia.
- Neff, J.W., R.S. Foster, and J.F. Slowey. 1978. Availability of sediment-adsorbed heavy metals to benthos with particular emphasis on deposit-feeding infauna. Technical Report D-78-42. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Overton, E.B., J.L. Laseter, W. Mascarella, C. Rasche, I. Nuiry, and J.W. Farrington. 1980. Photochemical oxidation of IXTOC I oil. Pages 341-386 in *Proceedings of the Conference on the Preliminary Scientific Results from the Researcher/Pierce Cruise to the IXTOC I Blowout*. NOAA, Office of Marine Pollution Assessment, Rockville, MD.
- Salomons, W., and H.N. Kerdijk. 1982. Pollutants in dredged material, their origin and impact on the environment. US/Dutch Memorandum of Understanding Meeting, New Orleans, LA.

- Sanders, H.L., J.F. Grassle, and G.R. Hampson. 1972. The West Falmouth Oil spill; I. Biology. Technical Report No. 72-20. Woods Hole Oceanographic Institution. Woods Hole, MA.
- Serne, R.J., and B.W. Mercer. 1975. Dredge disposal study, San Francisco Bay and Estuary. Appendix F: Crystalline Matrix Study. US Army Engineer District, San Francisco, San Francisco, CA.
- Walker, J.D., R.R. Colwell, and L. Petrakis. 1975. Biodegradation of petroleum by Chesapeake Bay sediment bacteria. *Can. J. Microbiol.* 22:423-428.
- Walker, J.D., P.A. Seesman, T.L. Hebert, and R.R. Colwell. 1976. Petroleum hydrocarbons: Degradation and growth potential of deep-sea sediment bacteria. *Environ. Pollut.* 10:89-99.
- Wier, C.F., and W.M. Walter. 1976. Toxicity of cadmium in the freshwater snail, *Physa grina*. *J. Environ. Qual.* 5:359-363.
- Wies, J.S., and P. Weis. 1976. Effects of heavy metals on fin regeneration in the killifish, *Fundulus heteroclitus*. *Bull. Environ. Contam. Toxicol.* 16:197-202.
- Weis, J.S., and P. Weis. 1979. Effects of mercury, cadmium, and lead compounds on regeneration in estuarine fishes and crabs. In W.B. Vernberg, A. Calabrese, F.P. Thurberg, and F.J. Vernberg (eds.), *Marine Pollution: Functional Responses*. Academic Press, New York.

APPENDIX C:

Note: When conducting physical or chemical analyses of the water column or the sediments, or chemical analyses of biota during the designation process, it is very strongly recommended that the procedures used be comparable to those used to evaluate material for disposal and for monitoring. To facilitate this consistency, Chapter 9 of the "Draft Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters" (USEPA/USACE 1990) has been incorporated herein as Appendix C. The reader is advised that the document is a draft, and the methods described may be changed when the document becomes final. At this time, however, they are considered to be the best and most appropriate.

**9.0 PHYSICAL ANALYSES OF SEDIMENT
AND CHEMICAL ANALYSES OF SEDIMENT, WATER AND TISSUE SAMPLES**

This chapter provides guidance on the selection of chemical and physical parameters to aid in evaluating the acceptability of dredged material for proposed ocean disposal, and the methods used to analyze these parameters.

Methods cited in this chapter may be used to develop the chemical information required. However, other methods may provide similar results, and the final choice of analytical procedures depends upon the needs of each evaluation. In all cases, state-of-the-art methods should be used.

Any dredged material from estuarine or marine areas contain salt. The salt can interfere with the results obtained from some analytical methods. Any methods proposed for the determination of parameters in sediment and water from estuarine or marine environments have to explicitly address steps taken to control salt interferences.

9.1 PHYSICAL ANALYSES OF SEDIMENT

Ocean dumping evaluations require that the physical characteristics of the dredged material be determined and used to help assess the impacts of dumping on the benthic environment and the water column. The physical analysis of sediment samples is the first step in the overall process of sediment characterization. The physical analyses provide general information on the physical characteristics of the dredged material and can be used to assess the behavior of these sediments after disposal. These data are also valuable in helping to identify appropriate control and reference sediments for biological tests. In addition, the physical parameters can be helpful in evaluating the chemical measurements that are made as a later step in the characterization process.

The general analyses that are recommended are (1) grain size, (2) total organic carbon (TOC), and (3) total solids/specific gravity.

Grain size analysis is a measure of the frequency distribution of the size ranges of the particles that make up the sediment (Plumb, 1981; Folk, 1980). The general size classes of gravel, sand, silt, and clay are the

most useful in describing the size distribution of particles in dredged material samples.

The total organic carbon content of sediment is a measure of the total amount of oxidizable organic material in a sample. The TOC method should be based on high temperature combustion, rather than chemical oxidation. Some classes of organic compounds are not fully degraded by chemical/UV techniques. The volatile and nonvolatile organic components make up the total organic carbon of a sample. Because inorganic carbon (e.g., carbonates and bicarbonates) can be a significant proportion of the total carbon in some sediment, the sample has to be treated with acid to remove the inorganic carbon prior to TOC analysis. The method of Plumb (1981) recommends HCl as the acid. An alternative choice might be sulfuric acid since it is nonvolatile, is used as the preservative, and does not add to the chloride burden of the sample. Whatever acid is used, it has to be demonstrated on sodium chloride blanks, that there is no interference generated from the combined action of acid and salt in the sample. The EPA Region II Laboratory at Edison, New Jersey, has also developed an acceptable method for TOC analysis available from U.S. Environmental Protection Agency, Region II, Surveillance and Monitoring Branch, Woodbridge Avenue, Edison, NJ 08837.

Total solids is a gravimetric determination of the organic and inorganic material remaining in a sample after it has been dried at a specific temperature. The total solids values are generally used to convert concentrations of the chemical parameters from a wet-weight to a dry-weight basis. The specific gravity of a sample is the ratio of the mass of a given volume of material to an equal volume of distilled water at the same temperature (Plumb, 1981). Because the specific gravity analysis requires a dry sample, it is usually performed in conjunction with the total solids determination. The specific gravity of a dredged material sample can be used to help predict the dispersal and settling characteristics of dredged material upon ocean disposal.

Quality control (QC) procedures for the general characterization of sediments are necessary to ensure that the data meet acceptable criteria for precision and accuracy. At a minimum, one triplicate analysis should be performed for every 20 samples analyzed except for TOC where all samples should be run in triplicate. In addition, one procedural blank per 20

samples should be run and the results reported for TOC analysis. Standards used for TOC determinations have to be verified using independent check standards to verify the accuracy of the results. Quality control limits have to be agreed upon for each analytical procedure, and have to be consistent with the overall quality control plan. Standard reference materials are not available for the determination of the physical parameters in sediments; however, where possible, laboratory standards should be analyzed with the same frequency as the triplicate analyses. Quality assurance (QA) is discussed in Chapter 13.

9.2 DETECTION LIMITS

The selection of appropriate method detection limits (MDLs) is important. MDLs should be lower than the appropriate values to which the data are to be compared for interpretation. The detection limits for an analyte should be no greater than one-third (one-half log unit) of the appropriate value for the analyte and matrix of concern. An MDL of one-fifth to one-tenth the appropriate value is desirable and sufficient in most cases. This is necessary to evaluate whether the concentration of the analyte is approaching the value critical to the decision-making process.

Further, the MDL has to be sufficiently below the appropriate value so that there is a diminished variability in numerical values in the vicinity of the appropriate value. Since no conclusion can be more certain than the least certain measurement, excessively low MDLs will not contribute to conclusions if sampling error is the dominant variable factor. For some contaminants such as dioxin, every effort has to be made to achieve consistent quantitation at the lowest possible level. The detection limits have to be documented and reported for all analyses.

9.3 CHEMICAL ANALYSES OF SEDIMENT

9.3.1 Selection of Analytical Targets (Sediment)

Chemical analysis provides information about the chemicals present in the dredged material that, if biologically available, could cause toxicity and/or be bioaccumulated. This information is valuable for exposure

assessment and for deciding which of the contaminants present in the dredged material to measure in tissue samples.

If the historical review conducted in Tier I (Section 4.1) fails to produce sufficient information to develop a suitable list of potential contaminants, a list of target chemicals has to be compiled.

There are many chemicals that could be included as target analytes. Target analytes should be selected from the priority pollutant list (Table 9.1) and the information obtained from the historical review. In the context of the regulations, analysis of PAH in dredged material should focus on those PAH compounds on the priority pollutant list (Clarke and Gibson, 1987). In addition, the target list should be expanded to include other contaminants that historical information or commercial and/or agricultural applications suggest could be present at a specific dredging site; for example, dioxins where industrial fires have occurred, and tributyltin near ships on which these compounds have been used.

9.3.2 Selection of Chemical Analytical Techniques (Sediments)

Once the list of target analytes for sediments has been established, the analytical methods for the analytes have to be determined. The methods will, to some degree, dictate the amount of sediment sample required for each analysis. However, guidelines for the amount of sample to be collected are presented in Table 9.2. These general sample sizes take into consideration that more than one analysis may be required for each group of analytes. The amount of sample used in an analysis affects the detection limits attainable using a particular method.

For priority pollutants in sediments, the method detection limits (MDL) provided by EPA (1986a) may be used as general guidelines. These detection limits are analytical goals rather than requirements. Site- or operation-specific objectives may make lower or higher detection limits appropriate. If lower MDLs are required, the analysis may require more sensitive instrumentation, larger sample sizes or additional cleanup/concentration steps. For most coastal sediments, suitable analytical methodology will control interferences such that required detection limits will be reached. A discussion of sediment MDL values is

TABLE 9.1. PRIORITY POLLUTANTS AND 301(h) PESTICIDES LISTED ACCORDING TO STRUCTURAL COMPOUND CLASS

Structural Compound Class	PP ^(a)	Pollutant	Structural Compound Class	PP ^(a)	Pollutant
Phenols	65	phenol	Phthalates	66	bis(2-ethylhexy)phthalate
	34	2,4-dimethylphenol		67	butyl benzyl phthalate
Substituted Phenols	21	2,4,6-trichlorophenol		68	di-n-butyl phthalate
	22	para-chloro-meta-cresol		69	di-n-octyl phthalate
	24	2-chlorophenol		70	diethyl phthalate
	31	2,4-dichlorophenol		71	dimethyl phthalate
	57	2-nitrophenol	Polychlorinated	106	PCB-1242
	58	4-nitrophenol	Biphenyls (PCB)	107	PCB-1254
	59	2,4-dinitrophenol	as aroclors	108	PCB-1221
	60	4,6-dinitro-o-cresol		109	PCB-1232
	64	pentachlorophenol		110	PCB-1248
Organonitrogen Compounds	5	benzidine		111	PCB-1260
	28	3,3'-dichlorobenzidine		112	PCB-1016
	35	2,4-dinitrotoluene	Miscellaneous	129	TCDD (dioxin)
	36	2,6-dinitrotoluene	Oxygenated Compounds	54	isophorone
	37	1,2-diphenylhydrazine			
	56	nitrobenzene	Pesticides	89	aldrin
	61	N-nitrosodimethylamine		90	dieldrin
	62	N-nitrosodiphenylamine		91	chlordan
	63	N-nitrosodipropylamine		92	DDT ^(a)
Low Molecular Weight Polynuclear Aromatic Hydrocarbons (PAH)				95	endosulfan ^(a)
	1	acenaphthene		98	endrin
	55	naphthalene		99	endrin aldehyde
	77	acenaphthylene		100	heptachlor
	78	anthracene		101	heptachlor epoxide
	81	phenanthrene		102	alpha-hexachlorocyclohexane
	80	fluorene		103	beta-hexachlorocyclohexane
High Molecular Weight PAH				104	delta-hexachlorocyclohexane
	39	fluoranthene		105	gamma-hexachlorocyclohexane
	72	benzo(a)anthracene		113	toxaphene
	73	benzo(a)pyrene		-	mirex ^(a)
	74	benzo(b)fluoranthene		-	methoxychlor ^(a)
	75	benzo(k)fluoranthene		-	parathion ^(a)
	76	chrysene		-	malathion ^(a)
	79	benzo(ghi)perylene		-	guthion ^(a)
	82	dibenzo(a,h)anthracene		-	demeton ^(a)
	83	ideno(1,2,3-cd)pyrene			
	84	pyrene	Volatile Halogenated Alkanes	6	tetrachloromethane
Chlorinated Aromatic Hydrocarbons				10	1,2-dichloroethane
	8	1,2,4-trichlorobenzene		11	1,1,1-trichloroethane
	9	hexachlorobenzene		13	1,1-dichloroethane
	20	2-chloronaphthalene		14	1,1,2-trichloroethane
	25	1,2-dichlorobenzene		15	1,1,2,2-tetrachloroethane
	26	1,3-dichlorobenzene		16	chloroethane
	27	1,4-dichlorobenzene		23	chloroform
Chlorinated Aliphatic Hydrocarbons				32	1,2-dichloropropane
	52	hexachlorobutadiene		44	dichloromethane
	12	hexachloroethane		45	chloromethane
	53	hexachlorocyclopentadiene		46	bromomethane
				47	bromoform
Halogenated Ethers	18	bis(2-chloroethyl)ether		48	dichlorobromoethane
	40	4-chlorophenyl ether		49	fluorotrichloromethane (removed)
	41	4-bromophenyl ether		50	dichlorodifluoromethane (removed)
	42	bis(2-chloroisopropyl)ether		51	chlorodibromomethane
	43	bis(2-chloroethoxy)methane			

TABLE 9.1. (Continued)

Structural Compound Class	PP ^(a)	Pollutant
Volatile Halogenated Alkenes	29	1,1-dichloroethylene
	30	1,2-trans-dichloroethylene
	33	trans-1,3-dichloropropene
	33	cis-1,3-dichloropropene
	85	tetrachlorethene
	87	trichlorethene
	88	vinyl chloride
Volatile Aromatic Hydrocarbons	4	benzene
	38	ethylbenzene
	86	toluene
Volatile Chlorinated Aromatic Hydrocarbons	7	chlorobenzene
Volatile Unsaturated Carbonyl Compounds	2	acrolein
	3	acrylonitrile
Volatile Ethers	19	2-chloroethylvinylether
		bis(chloromethyl)ether (Removed)
Metals	114	antimony
	115	arsenic
	117	beryllium
	118	cadmium
	119	chromium
	120	copper
	122	lead
	123	mercury
	124	nickel
	125	selenium
	126	silver
	127	thallium
	128	zinc
Miscellaneous	121	cyanide
	116	asbestos

- (a) PP = Priority Pollutant
(b) Includes DDT, DDD, and DDE
(c) Includes alpha-endosulfan, beta-endosulfan, and endosulfan sulfate.
(d) Chlorinated 301(h) pesticides that are not on the priority pollutant list.
(e) Organophosphorus 301(h) pesticides that are not on the priority pollutant list.

TABLE 9.2. SEDIMENT SAMPLE SIZE REQUIREMENTS
FOR CHEMICAL AND PHYSICAL ANALYSES

Analytical Parameter	Sediment Sample Size (g, wet wt.) Delivered to Laboratory
Organics	250
Metals	100
Miscellaneous	50 ^(a)
Grain size	100
Total organic carbon	50
Total solids/specific gravity	50

(a) Miscellaneous sample size should be increased if auxiliary analytes that cannot be included as part of the organic or metal analyses are added to the target list.

presented in Tetra Tech (1986a) and EPA (1986a). In any event, quality control data should corroborate the detection limits reached, and any discrepancies has to be justified by the data.

The recommended method for the analysis of semivolatile and volatile priority pollutants in sediment is available from Tetra Tech (1986a). Analyses for organics should always use capillary column gas chromatography (GC) or gas chromatography/mass spectrometry (GC/MS) techniques. These methods provide analytically sound techniques that yield accurate data on the concentrations of chemicals in the sediment matrix. The analytical techniques for semivolatile organic compounds generally involve the solvent extraction of the organic constituents from the sediment matrix and subsequent analysis, after clean-up, using gas chromatography (GC) or gas chromatography/mass spectrometry (GC/MS). The extensive clean-up is necessitated by the likelihood of (1) biological macromolecules, (2) sulfur from sediments with low or no oxygen, and (3) oil and/or grease in the sediment. The analysis of volatile organic compounds incorporates purge and trap techniques with analysis by either GC or GC/MS. If dioxin analysis is being performed, the methods of Kuehl et al. (1987) or Smith et al. (1984) should be consulted.

For many metals analyses, the concentration of salt may be much greater than the analyte of interest, and cause unacceptable interferences in certain analytical techniques. In such cases, the freshwater approach of acid digestion followed by inductively coupled plasma or graphite furnace atomic absorption spectroscopy needs to be coupled with appropriate techniques for controlling this interference. Further, it has to be remembered that Cr, Se, Sn, Sb, and As generally occur as anions with several possible oxidation states, while the elements Fe, Zn, Pb, Ni, Cd, and Cu occur as hydrated cations (also with different oxidation states possible). The Hg method in EPA (1986a) may be used for sediment analysis. For quantitation at lower levels, the gold amalgamation methods may be necessary. Tributyltin is analyzed by the method of Rice et al. (1987), and selenium and arsenic by the method of EPRI (1986).

The techniques for the analysis of chemical constituents have some inherent limitations for sediment samples. Interferences encountered as part of the sediment matrix, particularly in samples from heavily polluted areas, may limit the ability of a method to detect or quantify some

analytes. Consequently, the most selective methods using GC/MS techniques are recommended for all nonchlorinated organic compounds, because GC/MS analysis can often avoid problems due to matrix interferences. Gas chromatography/electron capture detector (GC/ECD) methods are recommended as the primary analytical tool for all polychlorinated biphenyl (PCB) and pesticide analyses because GC/ECD analysis will result in lower detection limits. Two-column GC/ECD confirmation of all analytes is recommended. Alternatively, GC/MS using selected ion monitoring (SIM) can be used for PCB and pesticide analysis. A total extraction of metal ions is not necessary. The standard aqua regia extraction yields consistent and reproducible results. A total extraction of the metals can only be achieved by acid fluoride, or flux fusion methods.

The traditional methods for the analysis of PCB quantify PCB as aroclor mixtures, which can result in errors in determining concentrations (Brown et al., 1984). The mixture of PCB congeners making up the aroclors changes due to physical, chemical and/or biological processes altering the distribution of individual congeners in the environment after release. Techniques that rely on quantification of PCB by aroclor assume that the distributions of PCB congeners found in environmental samples are identical to industrial formulations. This is not the case. In addition, aroclor determinations do not yield information on the potential biological significance of the PCBs (McFarland and Clarke, 1989). The most toxic PCB congeners fall mainly within the tetra-, penta-, and hexa-chlorobiphenyl isomer groups (McFarland et al., 1986). More meaningful biological and toxicological information about PCB concentrations and more accurate analytical chemistry data can be obtained by analyzing and quantifying PCBs as individual congeners or isomer classes (Cl_1 - Cl_{10}). Total PCBs can be determined by the sum of the individual congeners. This summation more accurately represents the PCB concentration in samples as shown in the National Oceanic and Atmospheric Administration's Mussel Watch Program (NOAA, 1989). PCB congener analytical methods are recommended for all analyses of PCB in sediments. Table 9.3 lists the congeners recommended for analysis based on environmental abundance, persistence, and biological importance (McFarland and Clarke, 1989). The preparation for analysis should follow the techniques described in Tetra Tech (1986a) or EPA (1986a), but the instrumental analysis and quantification of the PCBs

TABLE 9.3. POLYCHLORINATED BIPHENYL (PCB) CONGENERS RECOMMENDED FOR
QUANTITATION AS POTENTIAL CONTAMINANTS OF CONCERN

PCB Congener ^(a)	Congener Number ^(b)		
	Summation ^(c)	Highest Priority ^(d)	Second Priority ^(e)
2,4' diCB	8		
2,2',5 triCB	18		18
2,4,4' triCB	28		
3,4,4' triCB			37
2,2',3,5' tetraCB	44		44
2,2',4,5' tetraCB			99
2,2',5,5' tetraCB	52		52
2,3',4,4' tetraCB	66		
2,3',4',5 tetraCB			70
2,4,4',5 tetraCB			74
3,3',4,4' tetraCB	77	77	
3,4,4',5 tetraCB			81
2,2',3,4,5' pentaCB		87	
2,2',3,4',5 pentaCB		49	
2,2',4,5,5' pentaCB	101	101	
2,3,3',4,4' pentaCB	105	105	
2,3,4,4',5 pentaCB			114
2,3',4,4',5 pentaCB	118	118	
2,3',4,4',6 pentaCB			119
2',3,4,4',5 pentaCB			123
3,3',4,4',5 pentaCB	126	126	
2,2',3,3',4,4' hexaCB	128	128	
2,2',3,4,4',5' hexaCB	138	138	
2,2',3,5,5',6 hexaCB			151
2,2',4,4',5,5' hexaCB	153	153	
2,3,3',4,4',5 hexaCB		156	
2,3,3',4,4',5 hexaCB			157
2,3,3',4,4',6 hexaCB			158

Table 9.3 (Cont.)

PCB Congener ^(a)	Congener Number ^(b)		
	Summation ^(c)	Highest Priority ^(d)	Second Priority ^(e)
2,3',4,4',5,5' hexaCB			167
2,3',4,4',5',6 hexaCB			168
3,3',4,4',5,5' hexaCB	169	169	
2,2',3,3',4,4',5 heptaCB	170	170	
2,2',3,4,4',5,5' heptaCB	180	180	
2,2',3,4,4',5',6 heptaCB		183	
2,2',3,4,4',6,6' heptaCB		184	
2,2',3,4',5,5',6 heptaCB	187		187
2,3,3',4,4',5,5' heptaCB			189
2,2',3,3',4,4',5,6 octaCB	195		
2,2',3,3',4,5,5',6' octaCB			201
2,2',3,3',4,4',5,5',6 nonaCB	206		
2,2',3,3',4,4',5,5',6,6' decaCB	209		

(a) PCB congeners recommended for quantitation, from dichlorobiphenyl (diCB) through decachlorobiphenyl (decaCB).

(b) Congeners are identified by their International Union of Pure and Applied Chemistry (IUPAC) number, as referenced in Ballschmiter and Zell (1980) and Mullen et al. (1984).

(c) These congeners are summed to determine total PCB concentration following the approach in NOAA (1989).

(d) PCB congeners having highest priority for potential environmental importance based on potential for toxicity, frequency of occurrence in environmental samples, and relative abundance in animal tissues (McFarland and Clarke, 1989).

(e) PCB congeners having second priority for potential environmental importance based on potential for toxicity, frequency of occurrence in environmental samples, and relative abundance in animal tissues (McFarland and Clarke, 1989).

should be performed using standard capillary GC columns, on individual PCB isomers according to the methods in NOAA (1989) (see also Stalling, 1987; Dunn, 1984; Schwartz, 1984; Mullin, 1984). Based on quantitation of the congeners listed in Table 9.3, PCB concentrations should also be summed to give total PCBs in the sample according to the NOAA (1989) methods.

As stated earlier, the list of target analytes should include compounds that background and historical information suggest may be present. To further ensure that toxic compounds not included in the priority pollutant list are not overlooked in the chemical characterization of the dredged material, the analytical results should also be scrutinized by trained personnel for additional analytes that are not on the target list. The presence of persistent major "unknown" analytes on gas chromatograms (GC) or reconstructed ion chromatograms (GC/MS) should be noted. In such a case, methods involving GC/MS techniques for organic compounds are recommended for the identification of unknown chemicals.

9.3.3 Quality Control

Although Chapter 13 presents general quality control/quality assurance considerations, the EPA methods for the analysis of priority pollutants include detailed quality control procedures and requirements that are appropriate for discussion here. These guidelines should be followed rigorously throughout the chemical analyses. General quality control procedures should include the analysis of a procedural blank and a matrix spike along with every 10 - 20 samples processed. To measure analytical precision, one sample should be analyzed in triplicate for every 10 - 20 samples analyzed. The standard deviation and coefficient of variation should be reported. In addition, recoveries of surrogate spikes should be documented and all analytical instruments calibrated at least daily. All calibration data should be submitted for review.

Standard reference materials (SRM) should also be routinely analyzed, if available, to determine analytical accuracy. Standard reference materials may be obtained from the organizations listed in Table 9.4. One SRM sample should be analyzed with every batch of 10 to 20 samples. Some samples of SRMs for organic analytes include National Research Council of

TABLE 9.4. MARINE REFERENCE MATERIALS AND STANDARDS

Reference Material Needed	Inorganic Constituents	Organic Constituents
Addresses	<p>Marine Analytical Chemistry Standards Program National Research Council of Canada Division of Chemistry Montreal Road Ottawa, Ontario, Canada K1A0R9 Telephone: (613) 993-2359</p> <p>U.S. Department of Commerce National Institute for Standards and Technology Office of Standard Reference Materials Room B3111 Chemistry Bldg. Gaithersburg, MD 20899</p>	<p>Marine Analytical Chemistry Standards Program National Research Council of Canada Atlantic Research Laboratory 1411 Oxford Street Halifax, Nova Scotia, Canada B3H3Z1 Telephone: (902) 426-8280</p> <p>U.S. Department of Commerce National Institute for Standards and Technology Office of Standard Reference Materials Room B3111 Chemistry Bldg. Gaithersburg, MD 20899</p>

Canada (NRC) marine sediment HS-1 and HS-2 for PCB; NRC marine sediment HS-3, HS-4, HS-5, and HS-6 for PAH; and National Institute for Standards and Technology (NIST) SRM #1647 and SRM #1597 for PAH. SRMs for metals analyses include NBS estuarine sediment (SRM #1646); NRC marine sediments MESS-1, BCSS-1, and PACS-1; and International Atomic Energy Agency (IAEA) marine sediment SD-N-1/2(TM). Since new SRMs are appearing continuously, current listings of appropriate agencies should be consulted frequently. The QA program has to document the ability of the methods selected to cope with the high salt content of sediments.

9.4 CHEMICAL ANALYSES OF WATER

9.4.1 Recommended Analytical Targets (Water)

Analysis of seawater to determine the potential release of dissolved chemical constituents from the dredged material (standard elutriate) may be necessary to determine compliance with the regulations. Elutriate tests (Section 10.1.2.1) involve mixing dredged material with seawater and allowing the mixture to settle. The portion of the dredged material that is considered to have the potential to impact the water column is the supernatant remaining after undisturbed settling. Chemical analysis of the elutriate allows a direct comparison of the data to applicable marine water quality criteria. Analysis of seawater samples from the disposal site may be necessary to help interpret interaction between the water and sediment during disposal of the dredged material. When collecting samples for elutriate testing, consideration should be given to the large volumes of water and sediment required to prepare triplicate samples for analysis. In some instances when poor settling occurs, the elutriate preparation has to be performed successively several times to accumulate enough water for testing.

In selecting target analytes for water analyses, historical water quality information from the dredging site should be evaluated along with data obtained from the chemical analysis of sediment samples. The data from the chemical evaluation of the dredged material provide a known list of constituents that might affect the water column. All target analytes identified in the sediment chemical analyses should be initially considered

potential targets for water analysis. Nonpriority-pollutant chemical components that are found in measurable concentrations in the sediments should be included as targets for the water analyses if review of the literature indicates that these analytes have the potential to bioaccumulate in animals (i.e., have high K_{ow}s or BCFs) and are of toxicological concern.

9.4.2 Selection of Analytical Techniques (Water)

In contrast to freshwaters, there are generally not EPA approved methods for analysis of saline waters. Application of the freshwater methods to seawater will frequently result in much higher method detection limits (MDLs) than are common for freshwater unless care is taken to control the effects of salt on the analytical signal. It is therefore extremely important to ascertain a laboratory's ability to execute methods and attain acceptable MDLs in matrices containing up to three percent sodium chloride.

Once the list of target analytes for water is established, the methods for analysis should be selected. The water volume delivered to the laboratory for specific analytical methods may vary. A minimum of 1 L of elutriate should be delivered to the laboratory for metals analysis (as little as 100 mL may be analyzed). One liter of elutriate should be analyzed for organic compounds. For water samples from the dredging or disposal sites, 10 L water samples should be analyzed for organic analytes and 1 L water samples should be delivered for metals analyses. Additional water samples might be required for any supplemental target compounds that cannot be determined as part of the analyses for metal or organic priority pollutants. The size of the sample is one of the limiting factors in determining the detection limits for the water analyses. In some cases, the 10 L seawater volume for organic analysis will provide MDLs below the applicable marine water quality criteria. This will allow a direct comparison of the seawater field data to the water quality criteria. MDLs for these water analyses should be established on the assumption that the seawater MDLs should be lower than the water quality criteria concentrations. Laboratories participating in this program should routinely report MDLs achieved for a given analyte.

Many of the methods cited below for priority pollutants correspond to the methods established by EPA for fresh water analyses. Modifications or substitute methods (e.g., additional extract concentration steps, larger sample sizes, or concentration of extracts to smaller volumes) might be necessary to properly determine analyte concentration in seawater or to meet the desired MDLs.

Detailed methods for the analysis of organic and inorganic priority pollutants in water are referenced in the Federal Register (1984, Vol. 49, No. 209) and "Methods for Chemical Analysis of Water and Wastes" (EPA, 1982). Additional approved methods can be found in "U.S. EPA Contract Lab Program" (EPA, 1986b), APHA "Standard Methods for the Analysis of Water and Wastewater" (1989), ASTM "Annual Book of Standards, Part 31, Water" (1980), and Tetra Tech (1985). Most of these methods will require modification to achieve low MDLs in seawater. Analysis of the semivolatile organic priority pollutants involves a solvent extraction of water with an optional sample cleanup procedure and analysis using GC or GC/MS Tetra Tech (1986). The volatile priority pollutants are determined using purge and trap techniques and analyzed by either GC or GC/MS. If dioxin analysis is necessary, methods of Mehrle et al. (1988) should be consulted.

Other methods available for metals are: cadmium, copper, lead, iron, zinc, silver (Danielson et al., 1978); arsenic (EPRI, 1986); selenium and antimony (Sturgeon et al., 1985); very low levels of mercury (Bloom et al., 1983); tributyltin (Rice 1987).

A primary requirement of the analysis of seawater for inorganic and organic priority pollutants is obtaining detection limits that will result in usable, quantitative data that can subsequently be compared to applicable marine water quality criteria to determine compliance with the LPC. Many existing EPA methods for fresh water analysis need to be adapted to achieve environmentally meaningful detection limits in seawater. Particularly of concern are procedural blanks and matrix interferences caused by the salt in seawater. Some modifications to the analytical methods for organic compounds might be required to sufficiently lower the MDLs. For example, it is recommended that sample extracts be concentrated to the lowest possible volume prior to instrumental analysis, and that instrumental injection volumes be increased in order to lower the limits of detection for the analytical methods used. All PCB and pesticide analytes

should be analyzed by GC/ECD, since the GC/ECD methods are more sensitive to these compounds and will lower the detection limits. PCB should be quantified as specific congeners (Mullin et al., 1984; Stalling et al., 1987) and as total PCB based on the summation of particular congeners. Methods for specific PCB congener analysis are available from NOAA (1989). The congener method is accurate, provides lower detection limits, and is less subject to matrix interferences based on the selection of the individual PCB congeners used to quantify PCB.

The analysis of metals in seawater is subject to matrix interferences from sea salts, particularly sodium and chloride ions, when the samples are concentrated prior to instrumental analysis. The presence of salts in seawater samples might require the use of alternate analytical approaches to the EPA approved freshwater methods to achieve the desired MDLs. The gold amalgamation method with cold vapor Atomic Absorption Spectrophotometry (AAS) analysis is recommended to eliminate seawater matrix interferences for mercury analysis. Methods using solvent extraction and AAS analysis might be required to reduce seawater matrix interferences for the analysis of other target metals. Graphite furnace AAS techniques after extraction are recommended for the analysis of metals with the exception of mercury. Appropriate techniques should be used on the instruments to reduce salt interferences.

9.4.3 Quality Control

Chapter 13 presents a general discussion of appropriate quality assurance and control practices. The methods recommended for the analysis of priority pollutants in water include detailed quality control procedures and requirements. These guidelines should be followed closely throughout the chemical analyses. Minimum quality control procedures should include the analysis of a procedural blank and a matrix spike along with every 10 - 20 samples processed. Triplicate analysis of one sample and analysis of appropriate standard reference materials should be conducted with the same frequency as the blanks and matrix spikes. Standard reference materials for organic priority pollutants are not currently available for seawater, but reference materials for inorganics may be obtained from the organizations listed in Table 9.4. Seawater matrix spikes of target

analytes (e.g., seawater spiked with NIST SRM 1647 for PAH), should be used to fulfill analytical accuracy requirements. Some available standard reference materials for priority pollutant metals in seawater are NRC seawater CASS-1 and NRC seawater NASS-2.

Since many MDL goals might be well below what current freshwater methods are able to do, it is necessary that an appropriate part of the QA program require laboratories to establish their own MDLs and provide data to support their detection limits. It is also incumbent on participating laboratories to show that modifications of existing methods are adequately precise, accurate, and free of salt interference from sea water.

9.5 CHEMICAL ANALYSES OF TISSUES

9.5.1 Recommended Analytical Targets (Biota)

Bioaccumulation is evaluated by analyzing the tissue of the test organisms for contaminants that are selected from the list of target analytes as being of contaminants of concern for a specific dredged material. Sediment chemistry data and available information on the bioaccumulation potential of those analytes has to be interpreted to establish which compounds are contaminants of concern in the tissues of biota.

The n-octanol/water partition coefficient (K_{ow}) has traditionally been used to estimate the bioconcentration factors (BCFs) of many chemicals, including the priority pollutants, in organism/water systems (Chiou et al., 1977; Kenaga and Goring, 1980; Veith et al., 1980; Mackay, 1982).

When identifying organic contaminants of concern for bioaccumulation, a useful rule of thumb is that the potential for bioaccumulation increases as K_{ow} increases. This general relationship is often true for compounds with $\log K_{ow}$ less than approximately 6. Above this value there is less of a tendency for bioaccumulation potential to increase with increasing K_{ow} . Consequently, the relative potential for bioaccumulation of organic compounds can be estimated from the K_{ow} of the compounds. EPA (1985) recommends that compounds for which the $\log K_{ow}$ is greater than 3.5 be flagged for consideration for further evaluation of bioaccumulation potential. Based on the existing data, the organic compound classes of

priority pollutants with the greatest potential to bioaccumulate are polynuclear aromatic hydrocarbons (PAH), PCBs, pesticides, and some phthalate esters. Generally, the volatile organic, phenol, and organonitrogen priority pollutants are not readily bioaccumulated. Some exceptions might be the chlorinated benzenes and the chlorinated phenols. Table 9.5 indicates the relative bioaccumulation potential of organic priority pollutants based on K_{ow} . If PCBs or PAHs are identified for analysis in tissues, the guidance on selection of specific analytical target compounds in Sections 9.3.1 and 9.3.2 should be followed.

The priority pollutant metals that might tend to bioaccumulate based on available BCF data are mercury, copper, arsenic, cadmium, zinc, lead, and chromium. Table 9.6 ranks the bioaccumulation potential of the priority pollutant metals based on calculated BCFs. Tables 9.5 and 9.6 have to be used with caution, because they are based on calculated bioconcentration from water. Sediment bioaccumulation tests, in contrast, are concerned with accumulation from a complex medium via all possible routes of uptake. The appropriate use of the tables is to help in selecting contaminants of concern for bioaccumulation analyses by providing a general indication of the relative potential for various chemicals to accumulate in tissues.

The strategy for selecting contaminants of concern for the chemical analysis of tissue of organisms should include three criteria: (1) the target analyte is present at levels of potential concern in the sediment as determined by sediment chemical analyses, (2) the target analyte has a high potential to accumulate and persist in tissues, and (3) the target analyte is of toxicological concern.

Analytes that might have a lower potential to bioaccumulate, but which are present at very high concentrations in the sediments, should also be included in the target list because the bioavailability of the compound might increase as organisms encounter high levels in sediments. In addition, compounds of a high accumulation potential and of high toxicological concern should be considered, even if present at low concentrations in the sediment.

Nonpriority-pollutant chemical components that are found in measurable concentrations in the sediments should be included as targets for the

TABLE 9.5. POTENTIAL FOR BIOACCUMULATION OF ORGANIC PRIORITY
POLLUTANTS AND 301(h) PESTICIDES BASED ON
OCTANOL/WATER PARTITION COEFFICIENTS (K_{ow})^(a)

Pollutant	Octanol/Water Partition Coefficients (log K_{ow})
Di-n-octyl phthalate	9.2
Indeno(1,2,3-cd)pyrene	7.7
Benzo(ghi)perylene	7.0
PCB-1260	6.9
Mirex ^(b)	6.9
Benzo(k)fluoranthene	6.8
Benzo(b)fluoranthene	6.6
PCB-1248	6.1
2,3,7,8-TCDD (dioxin)	6.1
Benzo(a)pyrene	6.0
Chlordane	6.0
PCB-1242	6.0
4,4'-DDD	6.0
Dibenzo(a,h)anthracene	6.0
PCB-1016	5.9
4,4'-DDT	5.7
4,4'-DDE	5.7
Benzo(a)anthracene	5.6
Chrysene	5.6
Endrin aldehyde	5.6
Fluoranthene	5.5
Hexachlorocyclopentadiene	5.5
Dieldrin	5.5
Heptachlor	5.4
Heptachlor epoxide	5.4
Hexachlorobenzene	5.2
Di-n-butyl phthalate	5.1
4-Bromophenyl phenyl ether	5.1
Pentachlorophenol	5.0
4-Chlorophenyl phenyl ether	4.9
Pyrene	4.9
2-Chloronaphthalene	4.7
Endrin	4.6
PCB-1232	4.5
Phenanthrene	4.5
Fluorene	4.4
Anthracene	4.3
Methoxychlor ^(b)	4.3
Hexachlorobutadiene	4.3

TABLE 9.5. (Continued)

Pollutant	Octanol/Water Partition Coefficients (log K_{ow})
1,2,4-trichlorobenzene	4.2
Bis(2-ethylhexyl)phthalate	4.2
Acenaphthylene	4.1
Butyl benzyl phthalate	4.0
PCB-1221	4.0
Hexachloroethane	3.9
Acenaphthene	3.9
α -hexachlorocyclohexane	3.8
δ -hexachlorocyclohexane	3.8
β -hexachlorocyclohexane	3.8
γ -hexachlorocyclohexane	3.8
Parathion ^(b)	3.8
Chlorobenzene	3.8
2,4,6-trichlorophenol	3.7
β -endosulfan	3.6
Endosulfan sulfate	3.6
α -endosulfan	3.6
Naphthalene	3.6
Fluorotrichloromethane ^(c)	3.5
1,4-dichlorobenzene	3.5
1,3-dichlorobenzene	3.4
1,2-dichlorobenzene	3.4
Toxaphene	3.3
Ethylbenzene	3.1
N-nitrosodiphenylamine	3.1
P-chloro-m cresol	3.1
2,4-dichlorophenol	3.1
3,3'-dichlorobenzene	3.0
Aldrin	3.0
1,2-diphenylhydrazine	2.9
4-nitrophenol	2.9
Malathion ^(b)	2.9
Tetrachloroethene	2.9
4,6-dinitro-o-cresol	2.8
Tetrachloroethene	2.6
Bis(2-chloroisopropyl) ether	2.6
1,1,1-trichloroethane	2.5
Trichloroethene	2.4
2,4-dimethylphenol	2.4
1,1,2,2-tetrachloroethane	2.4
Bromoform	2.3
1,2-dichloropropane	2.3
Toluene	2.2

TABLE 9.5. (Continued)

Pollutant	Octanol/Water Partition Coefficients (log K_{ow})
1,1,2-trichloroethane	2.2
Guthion ^(b)	2.2
Dichlorodifluoromethane ^(c)	2.2
2-chlorophenol	2.2
Benzene	2.1
Chlorodibromomethane	2.1
2,4-dinitrotoluene	2.1
2,6-dinitrotoluene	2.0
Trans-1,2-dichloropropene	2.0
Cis-1,3-dichloropropene	2.0
Demeton ^(b)	1.9
Chloroform	1.9
Dichlorobromomethane	1.9
Nitrobenzene	1.9
Benzidine	1.8
1,1-dichloroethane	1.8
2-nitrophenol	1.8
Isophorone	1.7
Dimethyl phthalate	1.6
Chloroethane	1.5
2,4-dinitrophenol	1.5
1,1-dichloroethylene	1.5
Phenol	1.5
1,2-dichloroethane	1.4
Diethyl phthalate	1.4
N-nitrosodipropylamine	1.3
Dichloromethane	1.3
2-chloroethylvinylether	1.3
Bis(2-chloroethoxy)methane	1.3
Acrylonitrile	1.2
Bis(2-chloroethyl)ether	1.1
Bromomethane	1.0
Acrolein	0.9
Chloromethane	0.9
Vinyl chloride	0.6
N-nitrosodimethylamine	0.6

(a) Adapted from Tetra Tech (1985).

(b) 301(h) pesticides not on the priority pollutant list.

(c) No longer on priority pollutant or 301(h) list.

TABLE 9.6. POTENTIAL FOR BIOACCUMULATION OF TRACE METAL PRIORITY POLLUTANTS BASED ON EMPIRICAL MEAN BIOCONCENTRATION FACTORS (BCF)^(a)

Pollutant	log BCF ^(b)
Methylmercury	4.6
Phenylmercury	4.6
Mercuric acetate	3.5
Copper	3.1
Zinc	2.8
Arsenic	2.5
Cadmium	2.5
Lead	2.2
Chromium IV	2.1
Chromium III	2.1
Mercury	2.0
Nickel	1.7
Thallium	1.2
Antimony	ND
Cyanide	ND
Asbestos	ND
Silver	ND
Selenium	ND
Beryllium	ND

(a) Adapted from Tetra Tech (1986b).

(b) ND = no data.

tissue analyses if review of the literature indicates that these analytes have the potential to bioaccumulate in animals (i.e., have high K_{ow} s or BCFs) and persist in animal tissues, and are of toxicological concern.

9.5.2 Selection of Analytical Chemical Techniques (Biota)

At present, formally approved standard methods for the analysis of priority pollutants in tissues are not available. However, several studies conducted for EPA and other agencies have developed analytical methods capable of identifying and quantifying most organic and inorganic priority pollutants in tissues. The amount of tissue required for analysis is somewhat dependent on the analytical procedure. As a general guideline, 25 g (wet weight) of tissue should be delivered to the laboratory for organic analysis and 10 g delivered for metals analysis; an additional 25 g may be necessary for supplemental analyte determinations.

The detection limits achieved for target analytes in tissue depend on the sample size as well as the specific analytical procedure. The MDL presented in a particular analytical method should serve as goals for priority pollutant tissue analyses. MDLs should be determined for all analytes according to guidance in 40 CFR 136; Appendix A. Detection limits have to be specified based on the intended use of the data and specific needs of each evaluation.

The existing methods for the analysis of priority pollutants in tissue involve two separate procedures: one for organic compounds and another for metals. The recommended methods for the analysis of semivolatile organic pollutants are described in "Extractable Toxic Organic Compounds, Standard Analytical Procedures of the NOAA National Analytical Facility" (NOAA, 1989). These methods are currently being used in the NOAA National Status and Trends Program. The procedure involves serial extraction of homogenized tissue samples with methylene chloride, followed by alumina and gel permeation column cleanup procedures that remove coextracted lipids. An automated gel permeation procedure described by Krahn et al. (1988) is recommended for rapid, efficient, and reproducible sample cleanup. The methylene chloride extract is concentrated and analyzed for semivolatile

organic pollutants using gas chromatography with capillary fused-silica columns to achieve sufficient analyte resolution.

Chlorinated hydrocarbons (e.g., PCBs and chlorinated pesticides) should be analyzed by gas chromatography/electron capture detection (GC/ECD). It is recommended that PCBs be quantitated as specific congeners (Mullin et al., 1984; Stalling et al., 1987) and not by industrial formulations (e.g., arochlors) because the levels of PCBs in tissues result from complex processes including selective accumulation and metabolism. See the discussion of PCB in Section 9.3.2. Lower detection limits and positive identification of PCBs and pesticides can be obtained using chemical ionization mass spectrometry if necessary.

The same tissue extract is analyzed for other semivolatile pollutants (e.g., PAHs phthalate esters, nitrosamines, phenols, etc.) using gas chromatography/mass spectrometry (GC/MS) as described in NOAA (1989), Battelle (1985), and Tetra Tech (1986b). These GC/MS methods are similar to EPA Method 8270 for solid wastes and soils (EPA, 1986). The lowest detection limits are achieved by operating the mass spectrometer in the selected ion monitoring (SIM) mode. Decisions to perform analysis of nonchlorinated hydrocarbons and the interpretation of resulting data should consider that many of these analytes are readily metabolized by most fish and many marine invertebrates.

If analysis of tissue samples for volatile priority pollutants is necessary, analytical methods are cited in Tetra Tech (1986b). The lipid content of the biological material is of importance in the interpretation of bioaccumulation information. A lipid determination should be performed on all biota submitted for organic analyses and the method of Bligh and Dyer (1959) is recommended. If other methods are used, they should be referenced to results from Bligh and Dyer's method. If dioxin analysis is being performed, methods by Mehrle et al. (1988), Smith et al. (1984), or Kuehl et al. (1987) should be consulted.

The analysis for priority pollutant metals involves a nitric acid or nitric acid/perchloric acid digestion of the tissue sample and subsequent analysis of the acid extract using AAS or Inductively Coupled Plasma (ICP) techniques. Procedures for the digestion of tissue samples for priority pollutant metals can be found in Tetra Tech (1986b). The methods used in the NOAA Status and Trends Program (NOAA, 1989) may also be used and are

recommended when very low detection levels are required. Microwave technology may be used for tissue digestion to reduce contamination and improve recovery of metals (Nakashima et al., 1988). This methodology is consistent with tissue analyses performed for the NOAA Status and Trends Program except for the microwave heating steps. Mercury analysis requires the use of cold vapor AAS methods. The matrix interferences encountered in analysis of metals in tissue might require case-specific techniques for overcoming interference problems. If tributyltin analysis is being performed, the methods of Rice et al. (1987) or Uhler et al. (1989) should be consulted.

9.5.3 Quality Control

Chapter 13 presents a general discussion of appropriate quality assurance and control practices for tissue analysis. A procedural blank (to measure potential contamination from laboratory procedures) and a matrix spike (to measure the recoveries of the target analytes from a sample matrix) should be performed with each 10 - 20 samples. Triplicate analysis of one sample (to measure analytical precision) and appropriate standard reference materials (to measure analytical accuracy) should be performed with the same frequency as the blanks and matrix spikes. Standard reference materials for organic priority pollutants in tissues are currently not available. The National Institute for Standards and Technology (NIST) is presently developing standard reference materials (SRM) for organic analytes. Tissue matrix spikes of target analytes should be used to fulfill analytical accuracy requirements for organic analyses. Standard reference materials for priority pollutant metals include NRC dogfish liver tissue (DOLT-1), dogfish muscle tissue (DORM-1), and lobster hepatopancreas reference tissue (TORT-1); and IAEA fish flesh MA-A-2(TM) and mussel tissue MAM-2(TM). Marine reference materials and standards for inorganic constituents in tissue may be obtained from the organizations listed in Table 9.4.

9.6 REFERENCES

- APHA. 1989. Standard Methods for the Analysis of Water and Waste Water, 17th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation, Washington, DC.
- ASTM. 1980. Annual Book of Standards, Part 31, Water. American Society for Testing and Materials, Philadelphia, PA.
- Ballschmiter, K. and M. Zell. 1980. Analysis of polychlorinated biphenyls (PCB's) by glass capillary gas chromatography, composition of technical aroclor- and clophen-PCB mixtures. Fresenius. fuer analyt. chem., Vol. 302, pp. 20-31.
- Battelle. 1985. Method for semivolatile organic priority pollutants in fish. Final Report. EPA contract no. 68-03-1760.
- Bligh, E.G. and W.J. Dyer. 1959. A rapid method of total lipid extraction and purification. Can. J. Biochem. Physiol. 37:911-917.
- Bloom, N.S., E.A. Crecellius, and S. Berman. 1983. Determination of mercury in seawater at sub-nanogram per liter levels. Marine Chem. 14:49-59.
- Brown, J.F., Jr., R.E. Wagner, D.L. Bedard, M.J. Brennan, J.C. Carnahan, and R.J. May. 1984. PCB transformations in Upper Hudson sediments. Northeastern Environmental Science 3(3/4):267-279.
- Chiou, C.T., V.H. Freed, D.W. Schmedding, and R.L. Kohnert. 1977. Partition coefficient and bioaccumulation of selected organic chemicals. Environ. Sci. Technol. 11:475-478.
- Clarke, J.U. and A.B. Gibson. 1987. Regulatory Identification of Petroleum Hydrocarbons in Dredged Material; Proceedings of a Workshop. Miscellaneous Paper D-87-3, U.S. Army Corps of Engineer Waterways Experiment Station, Vicksburg, Miss.
- Danielson, L., B. Magnussen, and S. Westerland. 1978. An improved metal extraction procedure for determination of trace metal in seawater by atomic absorption spectrometry with electrothermal atomization. Anal. Chem. Acta. 98:47-5.
- Dunn, W.J., III, Stallings, D.L., Schwartz, T.R., Hogan, J.W., Petty, J.D., Johansson, E., and Wold, S. 1984. Pattern recognition for classification and determination of polychlorinated biphenyls in environmental samples. Anal. Chem. 56:1308-1313.
- EPA (U.S. Environmental Protection Agency). 1982. Methods for the Analysis of Water and Wastes. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, OH. 460 pp.

- EPA (U.S. Environmental Protection Agency). 1985. Technical Support Document for Water Quality-Based Toxics Control. U.S. Environmental Protection Agency, Office of Water Enforcement and Permits, Washington, DC. EPA 440/4-85-032.
- EPA (U.S. Environmental Protection Agency). 1986a. Test Methods for Evaluating Solid Waste. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC.
- EPA (U.S. Environmental Protection Agency). 1986b (revised July 1987). U.S. EPA Contract Laboratory Program--Statement of Work for Organics Analysis, Multi-Media, Multi-Concentration. IFB WA 87K236-IFB WA 87K238.
- EPRI (Electrical Power Research Institute). 1986. Speciation of selenium and arsenic in natural waters and sediments, Vol. 2. Battelle Pacific Northwest Laboratories. EPRI EA-4641.
- Folk, R.L. 1980. Petrology of Sedimentary Rocks. Hemphill Publishing Co., Austin, TX, 182 pp.
- Kenaga, E.E. and C.A.I. Goring. 1980. Relationship between water solubility, soil sorption, octanol-water partitioning, and concentration of chemicals in biota. In: J.G. Eaton, P.R. Parish, and A.C. Hendricks (eds.), Aquatic Toxicology, ASTM STP 707, pp. 78-115. American Society for Testing and Materials, Philadelphia, PA.
- Krahn, M.M., L.K. Moore, R.G. Bogar, C.A. Wigren, S.L. Chan and D.W. Brown. 1988. High performance liquid chromatography methods for isolating organic contaminants from tissue and sediment extracts. Journal of Chromatography 437: 161-175.
- Kuehl, D.W., P.M. Cook, A.R. Batterman, D. Lothenbach and B.C. Butterworth. 1987. Bioavailability of polychlorinated dibenzo-p-dioxins and dibenzofurans from contaminated Wisconsin River Sediment to Carp. Chemosphere 16,4:667-679.
- MacKay, D. 1982. Correlation of bioconcentration factors. Environ. Sci. Technol. 5:274-278.
- McFarland, V.A. and J.U. Clarke. 1989. Environmental occurrence, abundance, and potential toxicity of polychlorinated biphenyl congeners: considerations for a congener-specific analysis. Environ. Health Perspect. 81:225-239.
- McFarland, V.A., J.U. Clarke, and A.B. Gibson. 1986. Changing Concepts and improved methods for evaluating the Importance of PCB's as Dredged Sediment Contaminants. Miscellaneous Paper D-86-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

- Mehrle, P.M., D.R. Buckler, E.E. Little, L.M. Smith, J.D. Petty, P.H. Peterman, D.L. Stalling, G.M. DeGraeve, J.J. Coyle, and W.J. Adams. 1988. Toxicity and Bioconcentration of 2,3,7,8 Tetrachlorodibenzodioxin and 2,3,7,8 Tetrachlorodibenzofuran in Rainbow Trout. *Environ. Toxicol. Chem.* 7:47-62.
- Mullin, M.D., C.M. Pochini, S. McCrindle, M. Romkes, S.H. Safe, and L.J. Safe. 1984. High resolution PCB analysis: Synthesis and chromatographic properties of all 209 PCB congeners. *Environ. Sci. Technol.* 18:468-476.
- Mullin, M.D., et al. 1984. High resolution PCB analysis. *Environ. Sci. Technol.* 18:468-76.
- Nakashima, S., R.E. Sturgeon, S. N. Willie and S. S. Berman. 1988. Acid digestion of marine sample for trace element analysis using microwave heating. *Analyst.* 113.
- NOAA (National Oceanic and Atmospheric Administration). 1989. Standard Analytical Procedures of the NOAA National Analytical Facility, second edition. NOAA Technical Memorandum NMFS F/NWC-92, 1985-86. Contact: National Status and Trends Program, NOAA N/OMA32, 11400 Rockville Pike, Rockville, MD 20852.
- Plumb, R.H., Jr. 1981. Procedure for Handling and Chemical Analysis of Sediment and Water Samples. Technical Report EPA/CE-81-1, prepared by Great Lakes Laboratory, State University College at Buffalo, Buffalo, NY, for the U.S. Environmental Protection Agency/Corps of Engineers Technical Committee on Criteria for Dredged and Fill Material. Published by the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Rice, C., F. Espourteille, and R. Huggett. 1987. A method for analysis of tributyltin in estuarial sediments and oyster tissue, Crassostrea Virginica. *R. Appl. Organometallic Chemistry.* 1:541-544.
- Schwartz, T.R., Campbell, R.D., Stalling, D.L., Little, R.L., Petty, J.D., Hogan, J.W., and Kaiser, E.M. 1984. Laboratory data base for isomer-specific determination of polychlorinated biphenyls. *Anal. Chem.* 56:1303-1308.
- Smith, L.M., D.L. Stalling and J.L. Johnson. 1984. Determination of part-per-trillion levels of polychlorinated dibenzofurans and dioxins in environmental samples. *Anal. Chem.* 56:1830-1842.
- Stalling, D.L., T.R. Schwartz, W.J. Dunn, III, and S. Wold. 1987. Classification of polychlorinated biphenyl residues. *Anal. Chem.* 59:1853-1859.
- Sturgeon, R., S. Willie, S. Berman. 1985. Preconcentration of selenium and antimony from seawater for determination of graphite furnace atomic absorption spectrometry. *Anal. Chem.* 57:16-9.

- Tetra Tech, Inc. 1985. Bioaccumulation Monitoring Guidance: 1.
Estimating the Potential for Bioaccumulation of Priority Pollutants
and 301(h) Pesticides Discharged into Marine and Estuarine Waters.
Final Report. EPA Contract No. 68-01-6938.
- Tetra Tech, Inc. 1986a. Analytical Methods for U.S. EPA Priority
Pollutants and 301(h) Pesticides in Estuarine and Marine Sediments.
Final Report. EPA Contract No. 69-01-6938.
- Tetra Tech, Inc. 1986b. Bioaccumulation Monitoring Guidance: 4.
Analytical Methods for U.S. EPA Priority Pollutants and 301(h)
Pesticides in Tissues from Estuarine and Marine Organisms. Final
Report. EPA Contract No. 68-01-6938.
- Uhler, A.D., T.H. Coogan, K.S. Davis, G.S. Durell, W.G. Steinhauer, S.Y.
Freitas and P.D. Boehm. 1989. Findings of tributyltin, dibutyltin
and monobutyltin in bivalves from selected U.S. coastal waters.
Environ. Tox. Chem. 8:971-979.
- Veith, G.D., K.J. Macek, S.R. Petrocelli, and J. Carroll. 1980. An
evaluation using partition coefficients and water solubility to
estimate bioconcentration factors for organic chemicals in fish. In:
J.G. Eaton, P.R. Parish, and A.C. Hendricks (eds.), Aquatic
Toxicology, ASTM STP 707, pp. 116-129. American Society for Testing
and Materials, Philadelphia, PA.

APPENDIX D: CHIEF SCIENTIST'S GUIDE FOR AT-SEA OPERATIONS

Note: The information concerning the timing and organization of oceanographic survey cruises is provided in Appendix D for those environmental managers who have little or no experience with such cruises and yet are called upon to plan such an endeavor. The system provided is meant to be advisory, not mandatory.

CHIEF SCIENTIST'S GUIDE FOR AT-SEA OPERATIONS

This appendix is a discussion of at-sea activities, for use as a supplement to the main text. For sampling details refer to Part VII of the text.

PLANS PRIOR TO THE SURVEY CRUISE

Checklist of Precruise Responsibilities

Item 1

Assign to individual members of the survey party responsibility for the following:

- a. Having adequate sample holding bottles, vials, and foils aboard, along with labels, caps, and marking pens. Also, all preservatives (formalin, alcohol, hexane, etc.) should be aboard in ample quantities and stored safely.
- b. Ensuring that all sampling equipment (except the salinity-temperature-depth probe (STD) and current meter) is aboard: transmissometer, grabs, box corers, trawls, and plastic and stainless steel coring tubes for subsampling sediment. Also, see to it that the grab and box corer are in good working order. Extra trawl bags should be available, and a second box corer is advisable.
- c. Checking the STD and current meter. The probes of the STD should be checked and calibrated, especially for conductivity and dissolved oxygen. The current meter and STD cables can be damaged; they should be checked for continuity.
- d. Ensuring that every sample is properly labeled and stored. (This responsibility may be assigned to one person, with one or more helpers.)

Item 2

The Chief Scientist should discuss survey plans with the ship's Master. It should be understood that the Master has the last word regarding safety of ship and personnel and that the Chief Scientist can order the course of the ship within the safety limits. All explosive and/or flammable chemicals brought aboard the ship should be stored and handled under the auspices of the Master. The Chief Scientist should instruct his party, if necessary, that they should seek the cooperation of the ship's crew but not expect them to work as members of the survey party unless such assistance has been agreed upon by the Master.

Item 3

Prepare a station list including the number of activities at each station for the Master. Indicate which stations are anchor stations and indicate the duration of activities. On some of the longer anchor stations it may be advisable to shut the engines down, especially if it is a sizable ship.

Item 4

The Chief Scientist should plot on his hydrographic chart the location of any critical areas (spawning grounds, shellfish beds, or human amenities) prior to departure, since this information must come from the literature or conversations with local fishermen. This will become important after determination of the bottom current as to placement of the upstream and downstream sampling stations. A guide as to what critical distances are

involved might be as follows: if the current is flowing at a rate of 1 knot and 4 hr are allowed for mixing, as in the criteria on ocean dumping, the fine materials would travel no more than 4 nautical miles in this time. Thus, any amenities 5 nautical miles or more away are probably not matters of concern.

CONDUCTING THE SURVEY CRUISE

Step 1

The Chief Scientist must assist the Master in locating the site. When this has been done, start Step 2.

Step 2

Tasks. Immediately run Fathometer traces across the site to obtain needed information on bathymetry. Use these traces in arriving at the following decisions.

Decisions to be made at this point.

- a. Set the location of the two within-site sampling stations. It is advisable that the trawl stations not cross the box corer stations, although they may be adjacent.
- b. Locate the point, probably between the above two stations, where the speed and direction of the bottom current should be determined.

Step 3

Proceed to the current meter station and **anchor** the ship. Use fore and aft anchors, if possible.

Step 4

Immediately take an STD profile for temperature, salinity, and, if possible, dissolved oxygen. Note the presence or absence of a thermocline or halocline. If present, determine speed and direction of the current above and below the discontinuity, for this is a two-layered system.

Step 5

Take the water samples (upcurrent side of the ship) required for

- a. Dissolved Hg.
- b. Dissolved Cd, Pb, and Cu.
- c. Chlorinated hydrocarbons.
- d. Petroleum hydrocarbons.

Then take a vertical haul with the transmissometer.

Step 6

Take a current meter reading at positions indicated above for a period of at least 30 min. Attempt to estimate period of tidal cycle during measurement (refer to tide chart).

The bottom current should be measured at 1.5 m above the bottom (to avoid the much slower boundary layer).

Step 7

During the period of current measurements, observe the wind, noting particularly its direction (remember for wind currents the observer faces into the wind and reads direction; for water currents the direction is that of the flow, i.e., the observer faces downcurrent). Some estimate of its speed would be helpful, especially if this is correlated with sea state. White caps on waves appear at between 10 and 12 knots.

Step 8

Note the wave height and direction, particularly in relation to the wind. The wave period can be timed by noting the interval in seconds between the passing of successive crests or troughs at the ship.

Step 9

Tasks. Up anchor and proceed to the near downstream within-site station and anchor (a single point is acceptable here), preparing for sampling of the macroinfauna (and meiofauna) with a box corer or Smith-McIntyre grab.

- a. Obtain the first box core sample. If the sediment is sandy, it will probably be necessary to add weights to the corer. The corer should penetrate deeply enough into the sediments that the core length is great enough to prevent supernatant water from leaking out around the sides of the core. If this happens, reject the core and try again.
- b. If the sample is satisfactory, immediately shove the two plastic core tubes for meiofauna into the sediments and two each for sediment **before** draining off any water. Now siphon off excess water with a rubber hose. Next take samples for trace metals. Now remove the samples for PCBs and pesticides and petroleum hydrocarbons with stainless steel tubes or other similar devices. Then remove sediment and metal tubes and finally the meiofaunal tubes.

Decisions to be made at this point.

- a. Set the locations of the two downstream stations (0.5 and 4.5 nautical miles). If there is a critical area downstream and the bottom current is over 0.5 knot, the two stations should be on a line between the portion of the site most frequently used for disposal and the critical area.
- b. Now set the locations of the two upcurrent stations. If the current was found not to be very strong, it may be advisable to use only one upcurrent station, say, 0.5 nautical mile from the site, and shift the second station the same distance between site boundary and shore. If there are two downstream critical areas, then by all means shift the one upstream station on a line toward it.

Tasks.

- a. Now take the five box cores for the macroinfauna. Again, reject samples if the supernatant water runs down the side while the corer is being hoisted aboard. It will be advisable to take a sediment sample from the first two cores.
- b. Place the core in a sample-holding box; remove only the top 15 cm of the core and place in a plastic bucket. If the samples can be sieved in 24 hr, no preservative is necessary as long as they are kept cool. If they cannot be sieved within hours, they must be preserved in formalin.
- c. Take an STD profile. Be sure to note time and tide. Note wind and wave conditions.

Step 10

Up anchor and proceed to the far downcurrent outside-the-site station. Repeat the tasks of Step 9.

Step 11

Up anchor and proceed to the near downcurrent outside-the-site station and repeat the tasks of Step 9.

Step 12

Up anchor and proceed to the upcurrent within-site station and repeat the tasks of Step 9.

Step 13

Up anchor and proceed to the near upcurrent outside-the-site station and repeat the tasks of Step 9.

Step 14

Up anchor and proceed to far upcurrent outside-the-site station and repeat Step 12. If the decision was made to move this station to the line between site and shore, move there and sample. Meanwhile, the beam trawl should be rigged for immediate use.

When the last box corer sample is aboard, rig the winch, sheaves, and line for trawling.

Note: If the decision had been made to stay on anchor overnight at any of the sites sampled in Steps 9-14, then current meter readings should be taken every 3 hr through the night.

Step 15

Beam trawl station. Carry out the trawls in order from upcurrent across the site, and downcurrent.

- a. Upcurrent: start at the far (distal) station and trawl on the line toward the proximal upcurrent station. Keep trawl on bottom for 10 min at a speed between 1 and 2 knots.

- b. Site station: start at the upcurrent line and move on a line toward the proximal downcurrent station. Keep on bottom 10 min even if downcurrent boundary of the site is crossed.
- c. Downcurrent: start at the proximal station and trawl toward the distal station. Keep trawl on bottom for 10 min at a speed between 1 and 2 knots.

The beam trawl samples must provide specimens for several analyses; hence, they must be handled with considerable care, as follows:

- a. When the sample is airborne and before it is brought aboard to the deck, rinse as much sediment as possible from the cod end.
- b. After rinsing, lower the cod end over a large plastic tub with low walls (a child's plastic wading pool serves well) and pull the release cord on the bag.
- c. Take a picture of the spilled sample and immediately select specimens for metal analyses (plastic bag), PCB analyses (hexane-rinsed foil), and petroleum hydrocarbons (hexane-rinsed foil).
- d. Sort the sample into principal groups and place in plastic bags with preservative. Place all the plastic bags in a pail (plastic) with tight-fitting lid.

Step 16

If time is available, it would be advisable to take one more STD profile and current meter station.

APPENDIX E: BASIS FOR ESTIMATES OF SURVEY COSTS

Note: The monetary components in this time and charge aspect of survey cruises are purely relative. In recent years costs have been rising at a rate between 15 and 20 percent per annum. Nevertheless, the relative costs of the activities discussed in this appendix should remain much the same from year to year.

BASIS FOR ESTIMATES OF SURVEY COSTS

TIME REQUIREMENTS

Sampling

Any estimate of the hours or days of sampling required to prepare for, carry out, and complete the recommended site-designation survey must be based in part upon the size and depth of the preponderance of sites. Generally such sites can be surveyed from a day boat of moderate size. This means that the boat will dock each night, and the survey party will bunk ashore. Charter costs for day boats are generally lower than for more conventional oceanographic craft so that some savings can be obtained. Moreover, there is a real advantage in having a member ashore at all times to sieve samples, especially the bulky macroinfaunal samples. It is recommended that four members of the five-man team occupy posts on the boat, as will be discussed later.

Basing these estimates on the day boat and a five-man survey party, it should be possible to survey a site very effectively in 24 hr, as follows:

Box coring	12 hr
Bathymetry	2 hr
STD	2 hr
Current meter	2 hr
Trawls	2 hr
Eating	1.5 hr
Water samples	1 hr
Incidental observation	1 hr
Time slippage	<u>0.5 hr</u>
	24 hr

Even though the actual sampling could be accomplished in 24 hr, it is recommended that the survey (on a day boat) be carried out in three 8-hr days. It has been found that the serial days often permit better insights into current and circulation patterns and more efficient tying together of loose ends of sampling and recording of notes.

Preparation

Preparation time as computed here refers only to the time spent mobilizing the ship, including getting all samples and sampling/holding materials aboard, and the time needed to demobilize the ship. Preparatory time needed by the survey party at the home base is not calculable and, indeed, for these purposes is not relevant. Mobilization and demobilization time is important because it is one of the determiners of the duration of the ship lease. One should allow at least one survey party and one ship lease day for these necessary functions.

Ship Lease

The minimum duration of the ship lease will be 4 days, as follows:

Sampling	3 days
Mobilization and demobilization	<u>1 days</u>
	4 days

Another factor which may extend this time is that required for steaming from the ship's home dock to the survey dock. This may be negligible when the two docks are in the same harbor, but in other cases 1 or possibly 2 days will have to be added. Note also that no time has been added for weather contingencies. High wind and swell can make sampling of shallow sites impossible. Balanced somewhat against this time need, however, is the fact that if more than one site is to be surveyed from the ship, mobilization and demobilization time can be amortized among them. All things considered, it is probably best to allow a range of 5 to 6 ship-days per site. If a more conventional sleep-in vessel is used, the number of days can be reduced, assuming a 24-hr schedule is kept. Such a vessel will have to be used on deeper sites. Even so, not much savings of time will be effected because more stations and more water column samples will have to be taken. Moreover, additional survey party members will have to be added.

COST REQUIREMENTS

Boat

The cost of day boat lease per site is likely to range around \$8,700 including fuel.

Manpower

Sampling

A five-man survey party is recommended when a day boat is used. Four members will carry out the at-sea sampling, and the fifth member will carry out preliminary processing of samples at the dock. It is recommended that the survey party include the following:

Shipboard	{	Chief Scientist – oceanographer
		Oceanographer – biological oceanographer (fishes)
		Head Technician – biological oceanographer (invertebrate)
		Technician – chemical or geological oceanographer

Land Assistant Technician – biologist

The first two should have an advanced degree and 5 to 10 years of experience, including leadership of oceanographic cruises. In addition, some allowance must be made for visits and early participation of the Project Director in the field survey. This should be a senior person.

Allowing as much as 2 days for travel time, the manpower time cost of the field aspect of the survey is likely to run around \$5,000 including overhead.

Sample analysis in the laboratory

This cost should be estimated based on the usual charge for analyzing each type of sample, multiplied by the number of samples that must be analyzed. Then, the final cost estimate can be calculated on the basis of the typical site (40 days required for lab work). A typical site may range in size from 1 to 3 square nautical miles and is situated in water ≤ 20 m deep. Larger or deeper sites may cost more.

The tabulation below is an estimate based on six stations for each of two seasons.

<u>Parameter</u>	<u>Price Range</u>	<u>Number of Samples</u>	<u>Total Cost</u>
Water Column (per sample)			
Dissolved metals			
Cadmium and lead	\$ 55- 70	4	\$ 220- 280
Mercury	30- 40	4	120- 160
Pesticides and PCBs	165-185	4	660- 740
High molecular weight (HMW) hydrocarbons (aliphatics and aromatics by gas-liquid chromatography (GLC)	300-350	4	1,200- 1,400
Sediments (per sample)			
Grain size and human debris	40- 50	36	1,440- 1,800
Metals			
Cadmium and lead	60- 70	12	720- 840
Mercury	35- 45	12	420- 540
Pesticides and PCBs	250-300	12	3,000- 3,600
HMW hydrocarbons (aliphatics and aromatics) (GLC)	350-375	12	4,200- 4,500
Oil and grease	30- 45	12	360- 540
Total organic carbon	30- 45	12	360- 540
Biota			
Nematode/harpacticoid	125-150	24	3,000- 3,600
Macroinfauna	200-300	60	12,000-18,000
Macroepifauna	125-150	6	750- 900
Metals (2 species, 3 locations)			
Cadmium and lead	85-105	12	1,020- 1,260
Mercury	60- 80	12	720- 960
Pesticides and PCBs	300-350	12	<u>3,600- 4,200</u>
			\$33,790-43,860

Report preparation

The report should be prepared by the senior scientist, one assistant, and a secretary. Use of a computer can greatly simplify data management. It is estimated that 20 days will be required and that the cost including overhead would range around \$8,000.

Other Costs

Travel

1,000-mile round trip	
Transport	\$1,200
Per diem	<u>1,125</u>
	\$2,325

Travel transport is reduced if more than one site is done from a geographic location.

Materials and supplies

Field, laboratory	\$1,500
-------------------	---------

Fees

Fees for consulting firms center around 10% of total costs.

<u>Cost Summary (April 1989 Costs) - Two Visits</u>	
Ship	\$17,400
Manpower (field)	12,000
Lab analyses	43,860
Report	8,000
Travel	4,650
Materials	<u>1,500</u>
	\$87,410
Fee (10% of total)	<u>8,740</u>
	\$96,150

APPENDIX F: LIST OF EQUIPMENT SUPPLIERS

Note: This appendix presents a listing of manufacturers and suppliers of oceanographic equipment. Some of the more expensive items can be rented for short periods of time. The list of suppliers is far from complete, but most of the essential pieces of equipment needed for surveys can be obtained from those companies on the list.

LIST OF EQUIPMENT SUPPLIERS

A few equipment manufacturers and some of their respective products are listed below. This list is not intended to be complete nor in any way does an omission knowingly reflect on the quality of instrumentation or our preferences in regard to manufacturers. Consultation with the company by a procurement officer or his consultant should determine which manufacturer's product is best for a particular project.

<u>Manufacturer</u>	<u>Representative Products</u>
Benthos, Inc. Edgerton Drive North Falmouth, MA 02556 (617)540-5500	Blumer organic-free water bottles Blumer large-volume water bottles Grab sampler Boomerang grab Van Veen grab Benthic rock dredge Pipe dredge Sediment profiler (REMOTS) Underwater camera systems Remotely operated vehicle
EG&G Ocean Products PO Box 498 1140 Rt. 28A Cataumet, MA 02534	For instruments, see Neil Brown Instrument Systems, Inc.
Endeco, Inc. 13 Atlantis Dr. Marion, MA 02738 (617) 748-0366	Current meters
General Oceanics 1295 N.W. 163rd St. Miami, FL 33169 (305) 621-2882	Rosette water sampler Go-Flo water bottles Niskin water bottles Segmented water bottles Current meters
Guideline Instrument, Ltd. PO Box 98 Smith Falls, Ontario, Canada (613) 283-3000	Rosette water sampler Go-Flo water bottles Niskin water bottles Segmented water bottles Current meters
Hydrolab PO Box 50116 Austin, TX 78763 (512) 255-8841	STD-CTD Dissolved oxygen probe
Hydro Products, Inc. 11777 Sorrento Valley Rd. San Diego, CA 92121 (619) 453-2345	Water bottles Shipek and other grabs Nephelometer Transmissometer

<u>Manufacturer</u>	<u>Representative Products</u>
Hydro Products, Inc. (Cont'd)	Cameras Current meters
Inter Ocean Industries 3540 Aero Ct. San Diego, CA 92123 (619) 565-8400	STD-CTD Dissolved oxygen probe Water bottles Current meters
Kahl Scientific Instruments 737 West Main St. El Cajon, CA 92020 (619) 444-2158	Water bottles Box sediment grab Pietz-LaFond bottom grab Orange peel grab Screen top grab Smith-McIntyre grab Van Veen grab Benthic rock dredge Birge-Ekman dredge Petersen dredge
Montedoro/Whitney Corporation 2741-E McMillen Rd. San Luis Obispo, CA 93401 (805) 543-1233	Nephelometer Transmissometer STD Data loggers Telemetry
Mulligan Marine & Industrial Supply 3033 Sherwood Oaks Dr. Dickinson, TX 77539	General shipboard equipment
Neil Brown Instrument Systems, Inc. PO Box 499 Cataumet, MA 02534 (617) 563-9317	STD-CTD Dissolved oxygen probes Current meters Acoustic systems Navigation systems Acoustic data telemeters
Ocean Surveys Incorporated 91 Sheffield St. Old Saybrook, CT 06475 (203) 388-4631 or 100 East Water St. Wilmington, CA 90744	All kinds of oceanographic surveys and oceanographic equipment leasing
Oceanography Department Texas A&M University College Station, TX 77843 (409) 665-7211	Gray-O'Hara box corer

<u>Manufacturer</u>	<u>Representative Products</u>
<p>Tetra Tech, Inc.- Engineering Div. 630 North Rosemead Blvd. Pasadena, CA 91107 (818) 449-6400</p> <p>Wildlife Supply Co. 301 Cass St. Saginaw, MI 48602 (517) 799-8100</p>	<p>Oceanographic equipment leasing</p> <p>Fjarlie water bottles Kemmera water bottles Van Dorn water bottles Grab samplers Ponar grab Ekman bottom dredge Emery pipe dredge Petersen dredge Corers Plankton nets</p>